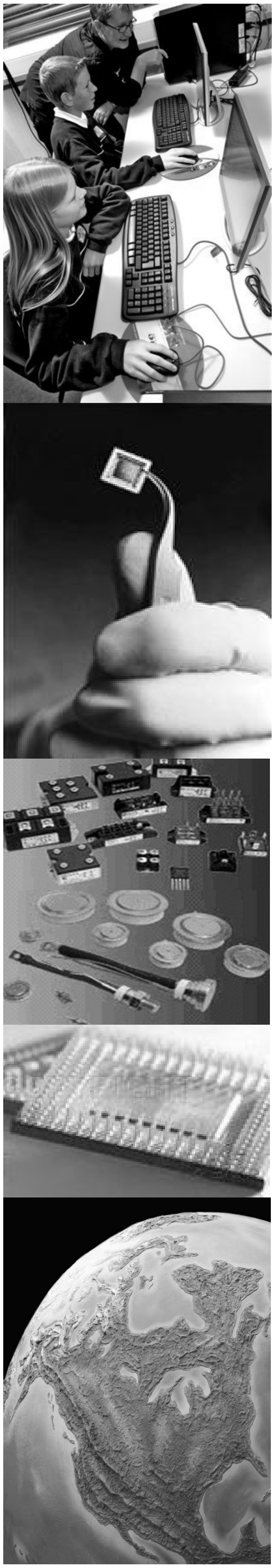

INITIAL STATEMENT OF REASONS FOR PROPOSED REGULATION TO REDUCE GREENHOUSE GAS EMISSIONS FROM SEMICONDUCTOR OPERATIONS

STATIONARY SOURCE DIVISION
MEASURES ASSESSMENT BRANCH

January 2009

State of California
AIR RESOURCES BOARD

INITIAL STATEMENT OF REASONS
F0R PROPOSED RULEMAKING

Public Hearing To Consider

ADOPTION OF PROPOSED REGULATION TO REDUCE GREENHOUSE GAS EMISSIONS FROM SEMICONDUCTOR OPERATIONS

To be considered by the Air Resources Board
On February 26, 2009

at

Cal/EPA Headquarters
1001 I Street
Sacramento, California

Air Resources Board
P.O. Box 2815
Sacramento, CA 95812

State of California
AIR RESOURCES BOARD

PROPOSED REGULATION TO REDUCE GREENHOUSE GAS EMISSIONS FROM SEMICONDUCTOR OPERATIONS

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ACRONYMS

AB	Assembly Bill
APCD	Air Pollution Control District
AQMD	Air Quality Management District
ARB/Board	Air Resources Board
BAAQMD	Bay Area Air Quality Management District
Cal/OSHA	California Occupational Safety and Health Administration
CAT	Climate Action Team
CC	Climate Change
CCA	California Clean Air Act
CCR	California Code of Regulations
CEQA	California Environmental Quality Act
CO_2	Carbon Dioxide
CFR	Code of Federal Regulations
CRF	Capital Recovery Factor
FTIR	Fourier Transform Infrared Spectroscopy
GHG	Greenhouse Gas
GWP	Global Warming Potential
HAP	Hazardous Air Pollutant
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HFE	Hydrofluoroether
HSC	Health and Safety Code
IPCC	Intergovernmental Panel on Climate Change
ISOR	Initial Statement of Reasons
Kg	Kilogram(s)
MMT CO_2e	Million Metric Tons of Carbon Dioxide Equivalents
MT CO_2e	Metric Tons of Carbon Dioxide Equivalents
MW	Molecular Weight
N_2O	Nitrous Oxide
NAAQS	National Ambient Air Quality Standards
NAICS	North American Industry Classification System
NESHAP	National Emission Standards for Hazardous Air Pollutants
NIOSH	National Institute for Occupational Safety and Health
OEHHA	Office of Environmental Health Hazard Assessment
OSHA	Occupational Safety and Health Administration
PFC	Perfluorocarbon
PPM	Parts Per Million
REL	Reference Exposure Level
ROE	Return On Owner's Equity
SB	Senate Bill
SCC	Source Classification Code
SCAQMD	South Coast Air Quality Management District
SIC	Standard Industrial Classification

ACRONYMS

Survey	2006 Survey of Semiconductor Industry
TAC	Toxic Air Contaminant
U.S. EPA	United States Environmental Protection Agency
UV	Ultraviolet
VCAPCD	Ventura County Air Pollution Control District
VOC	Volatile Organic Compound

EXECUTIVE SUMMARY

In this rulemaking, California Air Resources Board (ARB or Board) staff is proposing to reduce greenhouse gas (GHG) emissions, also referred to as fluorinated gases, from semiconductor and related devices operations (semiconductor operations). The proposed regulation to reduce the emissions of fluorinated gases with high Global Warming Potential (GWP) was developed in accordance with the discrete early action measure requirements set forth in the California Global Warming Solutions Act of 2006, Assembly Bill (AB) 32. The proposed regulation would be codified in title 17, California Code of Regulations, sections 95320 through 95326.

The proposed regulation would set new maximum allowable GHG emission limits for semiconductor operations. When fully implemented, GHG emissions would be reduced by 56 percent or 0.18 million metric tons of carbon dioxide equivalent (MMT CO_2e) per year. The annualized cost of this regulation is approximately $3.7 million, or about $21 per metric ton of CO_2e emissions reduced.

In developing this proposal, staff evaluated economic and environmental impacts and found no significant adverse impacts. Staff also found that reducing the emissions of fluorinated gases with high GWP would have a beneficial impact on climate change.

This Executive Summary provides a description of the staff's proposed regulation and explains the rationale for the regulation. The Executive Summary and subsequent chapters (Chapters I through VIII and Appendices A through C) constitutes the Initial Statement of Reasons for Proposed Rulemaking (ISOR) required by the California Administrative Procedures Act. In accordance with Government Code section 11346.2(a)(1), Chapter V provides a "plain English" summary of the proposal in more detail.

A. INTRODUCTION

1. What are semiconductor operations?

Semiconductor operation refers to the processing of semiconductor devices or related solid state devices. This may include, but is not limited to, the processing of diodes, zeners, stacks, rectifiers, integrated microcircuits, transistors, solar cells, light-sensing devices, and light-emitting devices. The types of operations include manufacturers, research and development organizations, and universities that do research and development. California has approximately 85 semiconductor operations; most are located in the Bay Area.

Semiconductor operations use fluorinated gases to process blank wafers into finished "chips." Chips contain multiple layers of integrated circuits that are formed after many process steps. In the course of processing wafers, fluorinated gases are used to clean chemical vapor deposition (CVD) chambers and etch circuits in the layers. Finished chips are used in various products ranging from computers and cell phones to automobiles.

Semiconductor operations vary widely in their wafer processing capacity, as well as type and size of wafers, use of fluorinated gases, vintage of processing tools, and use of emission control technology.

2. What existing regulations impact semiconductor operations?

Four districts regulate volatile organic compound (VOC) emissions from semiconductor operations. Emissions are controlled by applying improved emission control systems, using low VOC content materials, minimizing solvent losses and observing good business practices. District rules also include annual reporting and recordkeeping requirements, test methods for determining VOC content, and exemptions for small operations. The districts that have these rules and the respective rule numbers are:

- Bay Area Air Quality Management District, Rule 8-30;
- Placer County Air Pollution Control District, Rule 244;
- South Coast Air Quality Management District, Rule 1164; and
- Ventura County Air Pollution Control District, Rule 74.21.

Two other districts, Sacramento Metropolitan Air Quality Management District, and Santa Barbara County Air Pollution Control District have a few, small semiconductor operations that are not subject to VOC regulations.

3. Are there voluntary programs to reduce GHG emissions from semiconductor operations?

In 1996, Semiconductor Industry Association (SIA) member companies joined the U.S. EPA in signing a Memorandum of Understanding (MOU) agreeing to reduce the amount of GHG emissions. Under the MOU, member companies report GHG emissions to the U.S. EPA, share information regarding technology to reduce GHG emissions, and undertake research and development to determine if industry should set goals for GHG emission reductions.

In 1999, the World Semiconductor Council (WSC)[1] approved a perfluorocarbon (PFC) emissions reduction goal calling on member associations to reduce aggregate absolute emissions of GHGs from semiconductor operations by

[1] WSC members at the time of the signing consisted of the European Electronic Components Manufacturer Association (now the European Semiconductor Industry Association, or ESIA), the Electronic Industries Association of Japan (now the Japanese Semiconductor Industry Association, or JSIA), the Korean Semiconductor Industry Association (KSIA), and the Semiconductor Industry Association (SIA).

10 percent or greater from baseline[2] levels by 2010. Concurrently, the SIA negotiated a second voluntary PFC Reduction/Climate Partnership MOU with the U.S. EPA. This MOU applies to U.S. semiconductor operations and supports the WSC agreement for a collective 10 percent reduction in emissions by 2010.

B. STATUTORY AUTHORITY

1. What does California law say regarding GHG emissions?

In 2006, the Global Warming Solutions Act (AB 32) was signed into law. This law created a comprehensive, multi-year program to reduce GHG emissions in California. The California Health and Safety Code, commencing with section 38500, contains the provisions that apply to reducing the impacts of GHGs used in semiconductor operations. AB 32 requires ARB to develop regulations and consider market-based compliance mechanisms that will ultimately restore California's GHG emissions to the 1990 baseline year by 2020. The regulations developed under AB 32 must be designed to achieve the maximum technologically feasible and cost-effective reductions in GHG emissions. Beyond the requirements of AB 32, the Governor's Executive Order EO-S-03-05 calls for an additional GHG emissions reduction of 80 percent below 1990 levels by 2050.

AB 32 further requires immediate progress, described as discrete early action measures, to reduce GHGs. Discrete early action measures are defined as regulations adopted to reduce GHG emissions that become enforceable by January 1, 2010. Reduction of emissions from fluorinated gases with high GWP used in semiconductor operations has been designated as a discrete early action measure.

C. EMISSIONS AND GLOBAL WARMING IMPACTS

The ARB staff conducted a detailed survey of semiconductor operations to determine the emissions of fluorinated gases used in the CVD chamber cleaning and etching processes in 2006. The fluorinated gases used by semiconductor operations are considered to be high GWP gases.

1. What are the global warming potentials of fluorinated gases used by semiconductor operations?

Table ES-1 shows the GWP of the primary fluorinated gases used by semiconductor operations. Additional gases, used in small quantities, are listed in Chapter III. These GWP values are taken from the Intergovernmental Panel on Climate Change (IPCC) assessment reports.

[2] The baseline year for the ESIA, JSIA and SIA is 1995 and the KSIA baseline year is 1997. The Taiwan Semiconductor Industry Association (TSIA), joining the WSC after this agreement was signed, defined their baseline as the average of 1997 and 1999 emissions.

TABLE ES-1
GWP Values of Gases Used in Semiconductor Operations

Gas	GWP (SAR)*
hexafluoroethane (C_2F_6)	9,200
octafluoropropane (C_3F_8)	7,000
tetrafluoromethane (CF_4)	6,500
trifluoromethane (CHF_3)	11,700
octafluorocyclobutane (c-C_4F_8)	8,700
nitrogen trifluoride (NF_3)	17,200**
sulfur hexafluoride (SF_6)	23,900

* 100 year timeframe, IPCC Second Assessment Report (SAR)
** 100 year timeframe, IPCC Fourth Assessment Report.

The GWP of fluorinated gases used in semiconductor operations is high relative to that of CO_2. For example, the GWP of one kilogram of SF_6 is approximately 23,900 times greater than that of one kilogram of CO_2.

2. What are the GHG emissions from semiconductor operations?

Table ES-2 shows the GHG emissions in 2006 from fluorinated gas usage based on ARB's survey results. This table shows that 50 percent of the emissions are attributed to C_2F_6, the predominant gas used in CVD chamber cleaning.

Table ES-2
2006 Fluorinated Gas Use and Emissions

Fluorinated Gas	Use in Etch Process (Kg)	Use in CVD Chamber (Kg)	Etch Emissions (MMT CO_2e)	CVD Chamber Emissions (MMT CO_2e)	Percent of Total Emissions
C_2F_6	7,270	28,700	0.03	0.13	50
C_3F_8	1,280	7,500	0.007	0.02	8
CF_4	13,100	1,270	0.05	0.004	17
CHF_3	4,080	90	0.01	0.0008	4
c-C_4F_8	980	4,320	0.003	0.007	3
NF_3	4,480	15,090	0.01	0.006	5
SF_6	9,110	155	0.04	0.003	13
Total	**40,300**	**57,125**	**0.15**	**0.17**	**100**

In addition to the seven fluorinated gases listed above, the proposed regulation includes octafluorocyclopentene (C_5F_8), difluoromethane (CH_2F_2), octafluorotetrahydrofuran (C_4F_8O), hexafluoro-1,3-butadiene (C_4F_6), and carbon fluoride oxide (COF_2) in the definition of fluorinated gases. These additional fluorinated gases are included in the definition to ensure that all of the GHGs that are available for use in semiconductor operations are subject to the proposed regulation.

3. What are the estimated emission reductions from the proposed regulation?

Table ES-3 shows the estimated emission reductions and the percent complying market share by category for the proposed regulation. The Tier 1, 2 and 3 categories correspond to the large, medium and small semiconductor operations that are subject to varying emission standards in the proposed regulation. This table shows that the proposed regulation will reduce emissions by 0.18 MMT CO_2e or 56 percent. It also shows that fifty-seven percent of the wafers processed by Tier 1 operations already comply with the proposed emission standard. The complying market shares for the proposed emission standards for Tiers 2 and 3 are 43 percent and 34 percent, respectively.

Table ES-3
Emissions and Emission Reductions
CVD Chamber Cleaning and Etching Processes

Category*	Number of Operations in 2006	2006 Emissions (MMT CO_2e)	Percent Complying Market Share	Emission Reductions (MMT CO_2e)
Tier 1	5	0.17	57	0.11
Tier 2	11	0.08	43	0.03
Tier 3	12	0.05	34	0.04
Reporting Only	57	0.02	NA	NA
Total	**85**	**0.32**	**NA**	**0.18**

* Tier 1 operations process > 37.7 million square centimeters/year; Tier 2 operations process >3.7 and ≤ 37.7 million square centimeters/year; and Tier 3 operations process ≤ 3.7 million square centimeters/year.

4. What are the impacts of global warming?

Scientists predict that if the increase in GHG emissions continues unabated, temperatures will rise by as much as 10 degrees Fahrenheit by the end of this century. It is impossible to predict exactly how global warming will affect California's ecosystems and economy in the future. However, the expected physical changes will impact California's public health, economy and ecology.

These impacts include the exacerbation of air quality problems, a reduction in the supply and quality of water to the state from the Sierra snowpack, a rise in sea levels resulting in the displacement of thousands of coastal businesses and residences, damage to marine ecosystems, an increase in infectious diseases, asthma and other human health-related problems. Global warming will have detrimental effects on California's largest industries, including agriculture, wine, tourism, skiing, recreational and commercial fishing, and forestry.

The magnitude of the climate change problem justifies reductions from both large and small sources wherever such regulations are technically feasible and cost-effective. Emissions from semiconductor operations exceed the 0.1 MMT CO_2e de minimus threshold for source categories that is described in the Climate Change Scoping Plan that was unanimously approved by the Board on December 11, 2008.

D. DEVELOPMENT OF PROPOSED REGULATION

1. How were interested parties involved in developing the proposed regulation?

ARB staff formed two working groups to develop the proposed regulation. The industry working group included industry association and semiconductor fabrication representatives, process tool makers, GHG suppliers, emission control equipment manufacturers and the U.S. EPA. The second working group included the air districts with semiconductor operations. In addition to many technical experts, participation was open to any member of the public. Three meetings of the industry working group and conference calls with the air district working group were conducted to discuss the proposed regulation.

2. What other actions were taken to involve interested parties and collect necessary information?

Further outreach, in addition to the formation of the working groups, was conducted to identify and involve stakeholders in the development of this discrete early action measure. For example, in December 2007, ARB conducted a survey of the semiconductor industry (survey). The SIA and other stakeholders participated in developing the survey, which was sent to over 300 entities. Staff analyzed the survey data and contacted representatives of semiconductor operations to clarify survey responses and request additional information as needed. Survey results were posted on the ARB semiconductor website. The survey was used to identify affected companies, update the emissions inventory estimate, determine the volume of gases used in processing wafers, and collect information on the use of emission control technologies.

Staff also visited three semiconductor operations to learn more about semiconductor technology processes, the use of fluorinated gases, and emission control technologies. Additionally, staff conducted numerous meetings with individual stakeholders.

Staff conducted four public workshops in 2008, posting workshop notices and staff and industry presentations in advance of each workshop on ARB's semiconductor website. A List Serve was established to electronically inform over 450 interested parties of upcoming proceedings and actions.

3. How does the proposed regulation apply to semiconductor operations?

The proposed regulation applies to an owner or operator of a semiconductor or related devices operation that uses fluorinated gases or fluorinated heat transfer fluids. This includes the processing of diodes, zeners, stacks, rectifiers, integrated microcircuits, transistors, solar cells, light-sensing devices, and light-emitting devices. This listing is collectively referred to as semiconductors. The proposed regulation applies to the use of fluorinated gases during the etching of wafers, or selective removal of material from wafers. It also applies to the use of fluorinated gases to clean CVD chambers, in which insulating layers are laid down in alternation with conducting layers on the wafer.

The proposed regulation includes emission standards, and reporting and recordkeeping requirements. The proposed emission standards apply to semiconductor operations that emit more than 0.0008 MMT CO_2e per year. These operations, which include the large (Tier 1), medium (Tier 2), and small (Tier 3) manufacturers, account for 94 percent of the GHG emissions from the semiconductor industry. The reporting and recordkeeping requirements apply to all semiconductor operations in California.

Owners or operators of semiconductor operations would be required to comply with the emission standards by January 1, 2012. However, an operation replacing 150 millimeter (mm) wafer processing tools with 200 mm or larger tools would have until January 1, 2014 to comply with the emission standards. Providing more time for sources that are upgrading their wafer processing tools to comply with emission standards encourages early GHG reductions that are achievable with more efficient 200 mm or larger tools. The additional time also avoids the costly situation of installing abatement devices on old processing tools just before they are scheduled to be replaced. All semiconductor operations would be subject to the same timeframe for reporting and recordkeeping requirements.

4. What are the proposed emission standards?

The proposed emission standards for semiconductor operations are tiered, and vary depending upon the quantity of wafers (thin semiconductor material from which integrated circuits or "chips" are made) processed at a facility. The quantity of wafers processed is measured in square centimeters and includes all wafers processed at a facility, including those that do not pass inspection.

The proposed emission standards, expressed in kilograms of carbon dioxide equivalent (kg CO_2e) per square centimeter of wafer processed, are based on the quantity of wafers processed at an operation in a calendar year. They are grouped into three tiers as follows:

Tier 1: Up to 0.2 kg CO_2e per square centimeter of wafer processed may be emitted by operations processing greater than 37.7 million square centimeters of wafers in the calendar year.

Tier 2: Up to 0.3 kg CO_2e per square centimeter of wafer processed may be emitted by operations processing greater than 3.7 and less than or equal to 37.7 million square centimeters of wafers in the calendar year, provided operations were in existence prior to January 1, 2010.

Tier 3: Up to 0.5 kg CO_2e per square centimeter of wafer processed may be emitted by those operations processing less than or equal to 3.7 million square centimeters of wafers in the calendar year, provided operations were in existence prior to January 1, 2010.

Because Tier 2 and Tier 3 emission standards apply only to facilities in operation prior to January 1, 2010, all semiconductor operations established on or after that date will be required to meet the Tier 1 standard if they emit more than 0.0008 MMT CO_2e per year. Semiconductor operations installing emission control equipment must apply to the permitting agency for a permit.

5. Why are some semiconductor operations only subject to reporting and recordkeeping requirements?

Based on ARB's survey results, 57 semiconductor operations that emit 0.0008 MMT CO_2e or less per year account for six percent of the GHG emissions. Twenty-seven of these operations are small businesses, and all 57 operations account for only three percent of fluorinated gas usage. Our analysis indicates that the minor emission reductions achievable by subjecting these research and development operations to the emission standards are not cost-effective. Consequently, we are proposing to cap their emissions at the 0.0008 MMT CO_2e threshold level and subject them to annual reporting and recordkeeping requirements.

6. What are the reporting requirements?

Emissions reporting requirements include both initial and annual reporting. For the initial report, due to the permitting agency no later than March 1, 2011, semiconductor operations must report fluorinated gas emissions for the 2010 calendar year. For annual emissions reports, due to the permitting agency beginning March 1, 2012 and each year thereafter, semiconductor operations must report for the previous calendar year. In addition to emissions of fluorinated gases, the annual emissions report will collect information on the amounts of fluorinated gases used in CVD chamber cleaning and etching operations, the amount of semiconductor wafers processed, the use of process optimization, alternative chemistries, or equipment used to reduce fluorinated gas emissions, and information regarding the use of fluorinated heat transfer fluids. The initial emissions report and subsequent annual reports will be provided to the district having permit authority for the operation.

7. What are the recordkeeping requirements?

Recordkeeping provisions would require the owner or operator to maintain records on quantities of fluorinated gases and heat transfer fluids purchased or delivered, as well as records of emission control equipment malfunctions and failures. All records must be maintained at the facility and be readily accessible for inspection for at least three years.

8. What compliance options are available to semiconductor operations?

Semiconductor operations have the flexibility of choosing process optimization, alternative chemistries, abatement technologies, or a combination of these options to comply with the proposed regulation. Table V-2 in Chapter V shows which combinations of options are already being used by complying semiconductor operations. Two operations in Tiers 1 and 2 rely on all three compliance options to meet the emission standards. Three of the complying operations in Tier 3 rely on process optimization to meet the emission standard.

9. How does process optimization reduce GHG emissions?

Process optimization reduces fluorinated gas emissions from CVD chamber cleaning through the use of endpoint detectors and/or process parameter variation to find the optimum volume for fluorinated gas use. Process optimization continues to focus on CVD chamber cleaning because it is the greatest source of fluorinated gas emissions. Because the CVD chamber is cleaned when wafers are not in the chamber, this process can be optimized without negatively affecting wafer processing.

For CVD chamber cleaning, process optimization is estimated to reduce emissions from 10 to 56 percent compared to a baseline use of C_2F_6. It is the lowest cost strategy and may be more useful for older semiconductor operations that have not optimized the CVD chamber cleaning process.

10. How do alternative chemistries reduce GHG emissions?

Alternative chemistries is the substitution of one gas for another to achieve a net GHG benefit. This may occur through the use of lower GWP gases or through the use of higher GWP gases that are more efficient. Four gases, C_3F_8, c-C_4F_8, C_4F_8O and NF_3 are possible alternatives to the use of C_2F_6 for CVD chamber cleaning. The first three alternatives are "drop-in" replacements for C_2F_6, while NF_3 requires new machinery because of the aggressive nature of the gas. Table ES-4 compares the efficiency and emission benefits of alternative chemistries to that of C_2F_6 in CVD chamber cleaning.

Table ES-4
Alternative Chemistries Summary

C_2F_6 Replacement Chemistry	Utilization Efficiency* (%)	Emissions Reduction from Baseline C_2F_6 Process (%)
C_3F_8	30–60	12–70
c-C_4F_8	70–90	50–85
C_4F_8O	85–90	70–90
NF_3	60–80	20–90

*Utilization efficiency is the percentage of the gas used in the process. A 30 percent utilization efficiency means that 70 percent of the gas is emitted.

11. What are the primary alternative chemistries used by the semiconductor industry?

The largest portion of the GHG emission reductions achieved to date stem from substituting NF_3 for C_2F_6 in the CVD chamber cleaning process. Although NF_3 has a higher GWP than C_2F_6, less NF_3 is used in the CVD chamber cleaning process. The industry has developed remote plasma clean technologies to replace C_2F_6 for in-situ CVD chamber cleans and CF_4 used for nitride chamber cleaning. In a remote plasma system, the CVD chamber cleaning gas (NF_3) is raised to a high temperature before entering the CVD tool chamber. The plasma state is achieved using a radio frequency power source and the process is highly efficient. For in-situ CVD chamber cleaning, the gas flows directly into the CVD chamber and is raised to a high temperature within the chamber.

12. Do problems result from the use of alternative chemistries?

Implementing remote NF_3 chamber cleaning generates more fluorine (F_2) and hydrogen fluoride (HF) emissions than fluorocarbon-based cleans and, depending on the operation, may require additional treatment to remove these gases from the exhaust stream. Semiconductor operations typically treat F_2 and HF exhaust streams with water scrubbers. The additional loading on central end-of-pipe (EOP) water scrubbers may require modifications to the scrubber systems or installation of point-of-use (POU) scrubbers. Depending upon the operation's wastewater discharge limits, scrubber effluent may require treatment to decrease the fluoride loading. Many facilities have existing fluoride waste treatment facilities that remove fluoride by precipitation with some form of calcium, generating calcium fluoride.

13. What GHG emission control technologies are semiconductor operations using?

The most common technologies used to abate fluorinated gas emissions from semiconductor operations are high temperature and catalytic oxidation, and plasma destruction. Some operations include post-treatment to remove byproducts, such as F_2 and HF, produced during the abatement process.

Most emission control technologies apply to fluorinated gas emissions from both CVD chamber cleaning and etching processes, although several companies have developed plasma abatement systems specifically for emissions from etching.

14. What alternatives to the proposal were considered?

California Government Code section 11346.2 requires ARB to consider and evaluate reasonable alternatives to the proposed regulation and provide reasons for rejecting those alternatives. Staff considered two alternatives to the current proposal. These are no action and alternative standards. Staff determined that the alternatives did not meet the objective of Health and Safety Code section 38560 to achieve the maximum technologically feasible and cost-effective GHG emission reductions.

The "no action" alternative would forego or delay the adoption of the proposed rulemaking. This alternative was rejected as it would result in failure to make progress in reducing emissions of high GWP compounds from semiconductor operations.

The second alternative considered would impose separate emission standards for CVD chamber cleaning and etching processes. The emission standards for Tiers 1, 2 and 3 would reflect the lowest emitting operations for each process. The total emission reduction would increase from 0.18 to 0.22 MMT CO_2e. This alternative would impact more businesses, increasing the annual cost from $3.7 to $6.3 million. This option also increases the complexity of the regulation. Industry expressed concern that process specific emission standards would not be technically feasible and would not provide sufficient compliance flexibility. Staff concurs and, therefore, rejected this alternative.

E. ENVIRONMENTAL IMPACTS

The intent of the proposed regulation is to reduce GHG emissions from semiconductor operations. An additional consideration is the impact that the proposed regulation may have on the environment. The California Environmental Quality Act (CEQA) requires an agency to identify and adopt feasible mitigation measures that would minimize any significant adverse environmental impacts.

1. Are there any significant adverse environmental impacts from the proposed regulation?

The ARB staff has concluded that no significant adverse environmental impacts should occur from adoption of, and compliance with, the proposed regulation. This regulation reduces GHG emissions and is not expected to result in any significant adverse air quality, wastewater, or hazardous waste impacts. Therefore, no mitigation measures would be necessary.

2. Is this proposal consistent with ARB's Environmental Justice Policy?

The proposed regulation is consistent with our environmental justice policy to reduce health risk in all communities, including those with low-income and ethnically diverse populations, regardless of location. Potential risks from global warming due to GHGs can affect both urban and rural communities. Therefore, reducing emissions of GHGs from semiconductor operations will provide benefits to urban and rural communities in the State, including low-income and ethnically diverse communities. The decrease in GHG emissions will occur in areas where semiconductor manufacturing facilities are located, which are primarily outside of residential areas. Residents in close proximity to a manufacturing facility will not be adversely impacted.

As noted previously in the discussion on the use of alternative chemistries, some processes for reducing GHG emissions, such as the use of NF_3 for CVD chamber cleaning, may generate additional HF. Because HF is a toxic air contaminant (TAC), new and modified sources of HF emissions are subject to air district review. The air district review includes evaluating potential public exposure and health risk, mitigating potentially significant health risks resulting from these exposures, and decreasing health risk by improving the level of emissions control. Semiconductor operations located in the Bay Area Air Quality Management District (AQMD), for example, are subject to New Source Review of TACs when sources emit more than 540 pounds of HF per year.

Further public protection is provided through The Air Toxics "Hot Spots" Information and Assessment Act (AB 2588, 1987, Connelly) which requires stationary sources, such as semiconductor operations, to report the types and quantities of certain substances routinely released into the air. TACs, such as HF, are among the substances that are reportable. The goals of the Air Toxics "Hot Spots" Act are to collect emission data, identify facilities having localized impacts, ascertain health risks, notify nearby residents of significant risks, and reduce those significant risks to acceptable levels.

The compounds subject to the proposed regulation are GHGs. They are not carcinogens, hazardous air pollutants or ozone precursors. Staff's qualitative health risk assessment therefore concludes that public health will not be adversely affected by the regulation. A complete analysis of potential environmental impacts is contained in Chapter VI.

F. ECONOMIC IMPACTS

ARB evaluates the costs to comply with the proposed regulation by considering the potential impacts on profitability and other aspects of business, the cost-effectiveness of the proposed regulation, and the estimated cost impacts to consumers. Cost-effectiveness is one measure of a regulation's efficiency in reducing a given amount of emissions, and is often reported in dollars spent per metric ton of emissions reduced.

1. What is the cost-effectiveness of the proposed regulation?

Based on our analysis, staff estimates the overall cost-effectiveness of the proposed semiconductor regulation is approximately $21 per metric ton of CO_2e reduced. The cost-effectiveness of the Tier 1, 2, and 3 emission standards is shown in Table ES-5. Initial capital costs would be about $22 million with annual recurring costs of $850,000 (2007 dollars). These costs correspond to $3.7 million per year over the 10 year life of the regulation, or a total cost of $37 million. These figures include the cost of emission control equipment, operating costs, permit fees, reporting and recordkeeping.

Table ES-5
Cost-Effectiveness of Emission Standards by Tier

Tier	Total Annual Cost	Total Emission Reduction (MMT CO_2e)	Cost-Effectiveness
Tier 1	$2,280,000	0.11	$20.70
Tier 2	$700,000	0.03	$23.40
Tier 3	$680,000	0.04	$17.00
Total	**$3,660,000**	**0.18**	**$21**

2. What effect would this regulation have on the profitability of semiconductor operations?

Staff estimated profitability impacts by calculating the decline in the return on owner's equity (ROE). Assuming that semiconductor operations will have to absorb all of the costs associated with the proposed regulation, the average decline in ROE is 0.4 percent. This is well below the threshold that is considered to be a significant impact on the profitability of affected businesses. The decline in ROE is shown by tier in Table ES-6. ARB staff considers a decline in ROE of greater than 10 percent to be a significant economic impact. This threshold for determining significant impacts is consistent with the thresholds used by the U.S. EPA and others.

Table ES-6
Changes in Return on Owner's Equity

Tier	ROE Change
Tier 1	0.9%
Tier 2	0.05%
Tier 3	0.1%
Average	**0.4%**

Note: All changes in ROEs shown are negative which indicates a decline in profitability.

3. What is the average annual cost to semiconductor operations that do not currently meet the standards?

The average annual cost to those operations that would need to reduce emissions to meet the proposed emission standards is $280,000 in 2007 dollars.

4. Are there any small business impacts?

Five small businesses exceed the proposed emissions standards and would need to use a combination of emission reduction options. However, no significant adverse cost impacts are expected for these small businesses. The average annual cost to these businesses is $89,000 per year. Chapter VII contains a more thorough assessment of the economic impacts of the proposal.

G. FUTURE PLANS

1. What other activities is ARB planning?

If the Board approves the proposed regulation, ARB staff will develop a calculation tool to help the industry perform the IPCC Tier 2b emission calculations required by the proposal. Staff will also support the districts by offering secondary review of emission calculations, exchanging information on new technology developments, or helping resolve enforcement issues that may develop. Finally, ARB staff plans to evaluate the value of developing a sample format for the annual emissions reports to ease the reporting burden to industry and lessen the review time for district personnel.

The proposed regulation requires reporting on the use of fluorinated heat transfer fluids (HTF). ARB staff will continue to further research uses and quantify emissions of fluorinated heat transfer fluids (HTF) in semiconductor operations. HTFs have long atmospheric lifetimes and high GWP. To the extent that they evaporate into the atmosphere, their contribution to global warming is a concern.

H. RECOMMENDATION

We recommend that the Board adopt the proposed regulation for semiconductor and related devices operations.

I. INTRODUCTION

This report presents ARB staff's technical justification and analysis of the proposed measure to reduce fluorinated gas emissions from semiconductors and related devices (semiconductors). The proposed discrete early action measure would reduce the emissions of high Global Warming Potential (GWP) fluorinated gases, also referred to as greenhouse gases (GHGs), from the manufacturing or processing of semiconductors. The proposed rulemaking is designed in accordance with the discrete early action measure requirements as set forth in the California Global Warming Solutions Act of 2006 (AB 32, Health and Safety Code Section 38500 *et seq.*).

This report describes the rule development process and provides information on the following items:

- Enabling legislation and background;
- Background on semiconductor operations and voluntary efforts to reduce GHG emissions;
- The process used to develop the proposed rulemaking;
- A description of the proposed rulemaking and alternatives to the proposal;
- An analysis of the expected environmental and economic impacts from the proposed rulemaking; and,
- A summary of future activities.

The proposed regulation is provided in Appendix A of this document. A complete list of the acronyms used in this report is on page vi following the List of Figures.

A. OVERVIEW

The semiconductor industry consists of semiconductor manufacturers, research and development organizations, and universities as well as companies that supply the gases, process tools and emission control equipment used. Operations use fluorinated gases to process semiconductor wafers, usually round thin slices of silicon, which contain many individual integrated electronic circuits, or "chips." These chips contain multiple layers and are used in various products including computers, cell phones and automobiles.

Processing begins with a blank wafer and involves a series of steps which can number over 100 until a chip is complete. Organizations that process wafers vary widely in their production levels as well as type and size of wafers, volumes of fluorinated gases used, vintage of their processing tools, choice of chemistry and emission control technology used. Most operations are located in the Bay Area, although southern and central California businesses also exist.

Executive Order S-3-05, issued by Governor Schwarzenegger in June 2005, directed the Secretary of the California Environmental Protection Agency to form a Climate Action Team (CAT) to report on the impacts to California of global warming and progress toward meeting emission reduction targets set in the order. The CAT recognized the potential for reducing GHG emissions from the semiconductor industry in its March 2006 report to Governor Schwarzenegger and the Legislature. In October 2007, the California Air Resources Board (ARB or Board) designated GHG reductions from the semiconductor industry as a discrete early action measure, placing the strategy on an accelerated path to regulatory action.

B. ENABLING LEGISLATION

In 2006, Assembly Bill (AB) 32 was signed into law. This law, known as the Global Warming Solutions Act, created a comprehensive, multi-year program to reduce GHG emissions in California. AB 32 added section 1, division 25.5 (commencing with section 38500) to the California Health and Safety Code. These sections require ARB to develop regulations and consider market mechanisms that will ultimately reduce California's GHG emissions to the 1990 emissions level by 2020. AB 32 requires ARB to make immediate progress towards the reduction of GHG emissions. Specific discrete early action measures are to be identified and regulations are to be adopted and made enforceable by January 1, 2010. These early action measures must achieve the maximum technologically feasible and cost-effective reductions in GHGs from sources or categories of sources. Beyond the requirements of AB 32, the Governor's Executive Order EO-S-03-05 calls for an additional GHG reduction of 80 percent below the 1990 emissions level by 2050.

C. BACKGROUND

Four districts regulate volatile organic compound (VOC) emissions from semiconductor operations. Emissions are controlled by applying improved emission control systems, using low VOC content materials, meeting solvent loss minimization requirements and observing good business practices. District rules include annual reporting and recordkeeping requirements, test methods for determining VOC content, and exemptions for small operations. The applicable districts and rule numbers are:

- Bay Area Air Quality Management District, Rule 8-30;
- Placer County Air Pollution Control District, Rule 244;
- South Coast Air Quality Management District, Rule 1164; and,
- Ventura County Air Pollution Control District, Rule 74.21.

Two additional districts have small semiconductor operations within their jurisdictions, but do not regulate these operations. The districts are Sacramento Metropolitan Air Quality Management District and Santa Barbara County Air

Pollution Control District. Chapter IV, Table IV-3, shows the number of operations in the districts. The district rules exempt GHG emissions.

In California, GHG emission control by the semiconductor industry has only occurred voluntarily, through agreements with the United States Environmental Protection Agency (U.S. EPA) and a small number of California manufacturers. Three of the 85 semiconductor operations in California currently participate in the voluntary agreement with the U.S. EPA.

In 1996, Semiconductor Industry Association (SIA) member companies joined the U.S. EPA in signing a Memorandum of Understanding (MOU) agreeing to reduce GHG emissions, share information regarding technology to reduce GHG emissions, report GHG emissions to the U.S. EPA, and undertake research and development to determine if the industry should set goals for GHG emission reductions (SIA, 2007).

In 1999, the World Semiconductor Council (WSC)[3] approved a perfluorocarbon (PFC) emissions reduction goal calling on member associations to reduce aggregate absolute emissions of GHGs from semiconductor manufacturing operations by ten percent or greater from baseline[4] levels by 2010. Concurrent with the establishment of the WSC goal, the United States semiconductor industry negotiated a second voluntary PFC Reduction/Climate Partnership MOU with the U.S. EPA. This MOU applies to United States semiconductor manufacturing operations and supports the WSC agreement for a collective ten percent reduction in emissions by 2010 (SEMATECH, 2005).

In 2000, SIA member companies entered into a second MOU with the U.S EPA, agreeing to commit to reducing the total PFC emissions in the United States to ten percent below 1995 levels by the year 2010. Participating member companies are attempting to achieve these emission reductions nationwide through process optimization, development of alternative chemistries, capture/recovery, and emissions abatement (SIA, 2007).

In addition to the MOU, there are two other voluntary GHG programs. One is known as Climate Leaders, an industry/U.S. EPA partnership where companies commit to reducing emissions of GHGs by completing an inventory of their GHG emissions, setting reduction goals, and annually reporting progress to the U.S. EPA. A few semiconductor-related California companies participate in the partnership with each setting goals unique to the company. By participating,

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[3] WSC members at the time of the signing consisted of the European Electronic Components Manufacturer Association (now the European Semiconductor Industry Association, or ESIA), the Electronic Industries Association of Japan (now the Japanese Semiconductor Industry Association, or JSIA), the Korean Semiconductor Industry Association (KSIA), and the Semiconductor Industry Association (SIA).

[4] The baseline year for the ESIA, JSIA and SIA is 1995 and the KSIA baseline year is 1997. The Taiwan Semiconductor Industry Association (TSIA), joining the WSC after this agreement was signed, defined their baseline as the average of 1997 and 1999 emissions.

companies create a credible record of their accomplishments and receive U.S. EPA recognition as corporate environmental leaders.

The second effort is a global warming-related organization that includes semiconductor operations among its 210 members, known as the Silicon Valley Leadership Group (SVLG). The organization involves member companies and government officials to address broad policy issues affecting the economic health and quality of life in Silicon Valley. Reducing fluorinated gas emissions from semiconductor wafer processing is not specifically addressed, although lowering GHG emissions through greater energy efficiency and other means characterize SVLG member accomplishments.

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2. Semiconductor Industry Association. Perfluorocarbon Emissions by the Semiconductor Industry. May 30, 2007. (SIA, 2007)

II. STATUTORY REQUIREMENTS

In this chapter, we describe State law requirements related to setting GHG emission limits and how our proposal meets these criteria.

A. GHG REDUCTIONS THROUGH EARLY ACTIONS

AB 32 requires the Board to identify a list of discrete early action GHG emission reduction measures by June 30, 2007. Discrete early action measures are to be adopted and become legally enforceable (approved by the Office of Administrative Law) by January 1, 2010. The proposed measure to reduce emissions of fluorinated gases from semiconductor operations is one of the nine discrete early action measures listed by the Board.

B. AB 32 REQUIREMENTS

AB 32, The California Global Warming Solutions Act of 2006, creates a comprehensive, multi-year program to reduce GHG emissions in California. AB 32, at Health and Safety Code section 38560.5, requires that ARB adopt regulations by January 1, 2010 to implement discrete early action GHG emission reduction measures. These measures must "achieve the maximum technologically feasible and cost-effective reductions in greenhouse gas emissions" from the sources identified for early action measures. AB 32 contains additional standards in Health and Safety Code section 38562 that apply to regulations that will be adopted for general emissions reductions consistent with ARB's scoping plan. Among other things, this section requires that reductions must be real, permanent, quantifiable, verifiable, and enforceable. ARB is also required to adopt rules and regulations in an open, public process. While section 38562 does not directly apply to early action measures enacted under section 38560.5, ARB is interested in ensuring that its early action measures, such as the proposed regulatory action, meet the broader criteria for the GHG reduction regulations that will follow. For that reason, those criteria are summarized here, with staff's assessment as to why the proposed regulatory action meets them or is not specifically applicable to them.

The proposed regulatory action has been designated as a discrete early action measure and would reduce GHG emissions attributable to semiconductor operations by establishing emission standards for semiconductor processing. The following discussion explains why staff believes this proposed regulatory action meets the requirements of State law.

- **The State Board shall adopt rules and regulations in an open public process to achieve the maximum technologically feasible and cost-effective greenhouse gas emission reduction from sources or categories of sources.**

  Staff developed the proposed regulation to reduce GHG emissions from the semiconductor industry in consultation with affected industries in an open, public process through four public workshops and several individual consultation meetings. See Chapter V, Section A of this report for additional details.

  The proposed regulation is technologically feasible based on information from the ARB's survey of semiconductor operations, and discussions with semiconductor manufacturers and manufacturers of fluorinated gas emission control devices. Many semiconductor operations already use process optimization, alternative chemistries and control devices to minimize GHG emissions and comply with the proposed regulation. A detailed discussion of technological feasibility is included in Chapter III.

  The proposed regulation is cost-effective, with an estimated cost-effectiveness of $21 per metric ton of CO_2e reduced. These cost estimates are based on discussions with semiconductor manufacturers, air districts, gas suppliers, and emission control equipment manufacturers. A detailed discussion of economic feasibility is included in Chapter VII.

- **Design the regulations, including distribution of emissions allowances where appropriate, in a manner that is equitable, seeks to minimize costs and maximize the total benefits to California, and encourages early action to reduce greenhouse gas emissions.**

  The proposed regulation for semiconductor operations was designed to achieve the maximum benefit while minimizing the cost to the affected industry. ARB's survey of semiconductor operations was used to characterize the industry and develop emission standards that consider the size of the operation and the ability to reduce emissions in a cost-effective manner. The cost-effectiveness of the proposed regulation is about $21 per metric ton of CO_2e emissions reduced.

- **Ensure that activities undertaken to comply with the regulations do not disproportionately impact low-income communities.**

  The decrease in GHG emissions will occur in areas where semiconductor operations are currently located, which is mainly away from residential areas. Residents living near a semiconductor operation, regardless of income level, would not be disproportionately impacted.

- **Ensure that entities that have voluntarily reduced their greenhouse gas emissions prior to the implementation of this section receive appropriate credit for early voluntary reductions.**

The initial emissions reduction goal of 0.5 MMT CO_2e reflected the 2004 emissions inventory estimate of 0.88 MMT CO_2e. To establish a more recent and accurate inventory estimate, staff conducted a survey. The emission reduction goal was then adjusted to reflect reductions achieved through voluntary efforts. The adjusted reduction goal became 0.18 MMT CO_2e based on a 2006 inventory of 0.32 MMT CO_2e. We also considered voluntary efforts of operators to upgrade process tools. The proposed regulation allows an additional two years for compliance with the emission standards for any operation replacing older process tools with newer tools. This additional time alleviates the expense of installing abatement equipment for older tools that would soon be no longer in use.

- **Ensure that activities undertaken pursuant to the regulations complement, and do not interfere with, efforts to achieve and maintain federal and state ambient air quality standards and to reduce toxic air contaminant emissions.**

The proposed GHG emissions limits are not expected to cause an increase in the emissions of criteria pollutants or toxic air contaminants (TACs) with the possible exception of a slight increase in oxides of nitrogen (NO_x) emitted from certain types of abatement equipment. The proposed regulation will not interfere with district requirements for controlling VOC and TAC emissions from semiconductor operations because GHG emissions are not subject to district rules.

- **Consider cost-effectiveness of these regulations.**

The cost-effectiveness of the proposed emission limits is about $21 per metric ton of CO_2e reduced. See Chapter VII, Economic Impacts of Proposed Regulation, and Appendix C for a more detailed description.

- **Consider overall societal benefits, including reductions in other air pollutants, diversification of energy sources, and other benefits to the economy, environment, and public health.**

The proposed emissions limits for semiconductors are not expected to cause any significant adverse impacts to society or the environment. California will benefit from the reduction of GHG emissions. The proposed regulation will not cause a significant increase in VOC or TAC emissions, however, a slight increase in NO_x emissions may occur. No increase to the solid waste stream is anticipated. See Chapter VI for a more detailed discussion.

- **Minimize the administrative burden of implementing and complying with these regulations.**

  The administrative burden to manufacturers of complying with the proposed regulation is minimal as it has very few administrative requirements. The air districts would likely enforce the proposed regulation since these manufacturers are already subject to district permit and control requirements for VOCs and TACs. We are proposing to develop tools to calculate emissions and standardize the reporting format to ease the administrative burden on industry and the air districts.

- **Minimize leakage.**

  Leakage occurs when an emission limit set by the State causes manufacturing or other activities to be displaced outside of California. If leakage were to occur, jobs and other economic benefits to California would be lost. According to information provided by industry associations, the number of semiconductor manufacturing operations in California has already declined because manufacturers have relocated to other states and overseas. No, or minimal, leakage is expected from the proposed regulation based on discussions with the California semiconductor manufacturing industry. Therefore, the regulation would not create a situation where a manufacturer located in California would be placed in a competitive disadvantage compared to manufacturers out-of-state.

- **Consider the significance of the contribution of each source or category of sources to statewide emissions of greenhouse gases.**

  Semiconductor operations emitted 0.32 MMT CO_2e in 2006. This exceeds the 0.1 MMT CO_2e significance threshold for source categories that the Board approved in the Scoping Plan. The projected reductions that will be achieved are about 0.18 MMT CO_2e per year. While this reduction is somewhat modest, it is necessary to achieve the long term GHG emission reduction goals. When the reduction is considered in conjunction with current and future GHG emission reductions in other sectors, the total reductions are significant. The proposed regulation considers the minimal impacts of sources emitting under 0.0008 MMT CO_2e per year by exempting them from emission standards and only subjecting them to reporting and recordkeeping requirements.

- **The greenhouse gas emission reductions achieved are real, permanent, quantifiable, verifiable and enforceable by the state board.**

  We believe that the emissions and emission reductions for semiconductor operations are real since they were determined from gas usage data submitted by manufacturers and research and development organizations in the affected industry. The data were submitted in accordance with State law and were certified by an officer of the company whose data was submitted. The GHG emissions and reductions were quantifiable by using the Tier 2b method in the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories and based on GWP values defined by the IPCC Second Assessment Report (IPCC, 1996). The GHG reductions are verifiable through annual reporting and recordkeeping requirements included in the proposed regulation. These requirements also support enforcement efforts. Sources installing abatement devices to comply with the proposed emission limits are subject to district permitting requirements. Once the proposed regulation is approved by the Office of Administrative Law, the proposed emission limits will become State law.

- **For regulations…….the reduction is in addition to any greenhouse gas emission reduction otherwise required by law or regulation, and any other greenhouse gas emission reduction that otherwise would occur.**

  The proposed emissions limits for semiconductor operations are the first GHG emissions limits affecting this industry. No other State, federal, or other requirements, specific to the manufacturing in California and affecting emissions of GHGs, are known to exist.

- **If applicable, the greenhouse gas emission reduction occurs over the same time period and is equivalent in amount to any direct emission reduction required pursuant to this division.**

  This requirement is not applicable to the proposed emission limits for semiconductor operations. This regulation achieves its emission reductions as direct emissions.

- **The state board shall rely upon the best available economic and scientific information and its assessment of existing and projected technological capabilities when adopting the regulations required by the law.**

  ARB staff used the best available economic and scientific information to develop the proposed regulation for reducing GHG emissions from semiconductor operations. Chapter VII includes a detailed description of the economic impacts of the proposed emission limits. Chapters III and IV discuss processes to be regulated and estimated emissions and emission reductions, respectively.

III. SEMICONDUCTOR OPERATIONS AND PROCESSES

This chapter provides an overview of semiconductor chamber cleaning and etching processes, and a brief description of the fluorinated gases used in these operations.

A. SEMICONDUCTOR OPERATIONS

The manufacturing of semiconductors involves a series of sequential processes such as photomask creation, photoresist coating, Chemical Vapor Deposition (CVD) and CVD chamber cleaning, plasma etching, photoresist stripping, transistor formation, metallization, and wafer inspection. Two of these processes, CVD chamber cleaning and plasma etching, use plasma-generated fluorinated gases. The gases react at the surfaces of process equipment and semiconductor wafers to remove deposited materials from process chamber walls (CVD chamber cleaning) or selectively create circuitry patterns on wafers (plasma etching). There may be over 100 processing steps, of which a number use fluorinated gases, in forming complex circuits (Van Zant, 2004). The fluorinated gases include, but are not limited to:

- hexafluoroethane (C_2F_6);
- octafluoropropane (C_3F_8);
- octafluorocyclopentene (C_5F_8)
- tetrafluoromethane (CF_4);
- trifluoromethane (CHF_3);
- difluoromethane (CH_2F_2);
- octafluorocyclobutane (c-C_4F_8);
- octafluorotetrahydrofuran (C_4F_8O);
- hexafluoro-1,3-butadiene (C_4F_6);
- carbon fluoride oxide (COF_2);
- nitrogen trifluoride (NF_3); and,
- sulfur hexafluoride (SF_6).

In the CVD process, chemicals are used to produce high-purity, high-performance solid materials. Extremely thin films (layers) that are only billionths of a millimeter thick are formed on wafers. Many layers are necessary to create an intricate pattern of transistors and semiconductor circuitry. Over time, residual deposition gases form on the walls of the CVD chamber tool and must be removed to prevent particle contamination and reduce the percentage of nonfunctioning die per wafer.

Figure III-1 shows a worker loading 200 millimeter wafers into processing equipment.

Figure III-1 - Fab Worker

Figure Courtesy of March Plasma Systems.

CVD chamber cleaning requires the use of high GWP fluorinated gases because the fluorine molecules are needed to break the bond of the residue with the walls. Typical fluorinated gases used include, but are not limited to, CF_4, C_2F_6, C_3F_8, and NF_3 (U.S. EPA, 2001). One option for cleaning the tool is to use a remote plasma system where the gas is raised to a high temperature before entering the tool chamber. The plasma state is achieved using a radio frequency power source. The other option requires the gas to flow directly into the CVD chamber, then striking a high temperature within the chamber. This is referred to as in-situ plasma.

In the etching process, layers are chemically removed from the surface of a wafer. Unlike the CVD process where the entire wafer is coated, in the etching process the wafer must be oriented so the ions remove material from every die on the wafer. This process aids in forming transistors, diodes, and other electrical components. Every wafer undergoes many etching steps where high GWP gases are applied before it becomes a series of chips.

These processes are also used by universities that experiment with wafer processing and by research and development (R&D) operations that work with wafer manufacturing companies.

Initially, chlorofluorocarbons (CFCs) were used in these processes. With the signing of the Montreal Protocol in 1987 and the phase out of ozone depleting substances in the early 1990s, fluorinated gases have replaced CFCs (U.S. EPA, 2006). Fluorinated gases are preferred because the fluorine atom's strong bonding energy effectively removes material that has either bonded to the CVD chamber wall or to the wafer, or substrate material in wafer etching. However, 10 to 80 percent of the fluorinated gases can pass through the manufacturing tool chambers unreacted and be released into the air (SEMATECH, 2005).

Approximately 53 percent of the fluorinated gas emissions from semiconductor operations occur during CVD chamber cleaning and 47 percent during etching (ARB, 2007).

B. CHEMICAL VAPOR DEPOSITION AND CHAMBER CLEANING

As noted previously, semiconductor manufacturers, universities and R&D operations use the CVD process to layer thin films onto wafers. The wafer material in predominant use is silicon, although many non-silicon materials can be used such as gallium arsenide, gallium nitride, zinc selenide, and germanium. The wafer substrate is exposed to one or more gaseous molecules, called volatile precursors due to their high reactivity. The gases react with the surface to deposit a layer of material. Examples of material deposited include: silicon, carbon fiber, silica, tungsten, silicon nitride and titanium nitride (Wikipedia, 2008).

Figure III-2 shows how the volatile precursors react with the substrate. Some move downward and bond to the substrate, while others are removed as effluent.

Figure III-2
Gas Molecule Reaction with Substrate

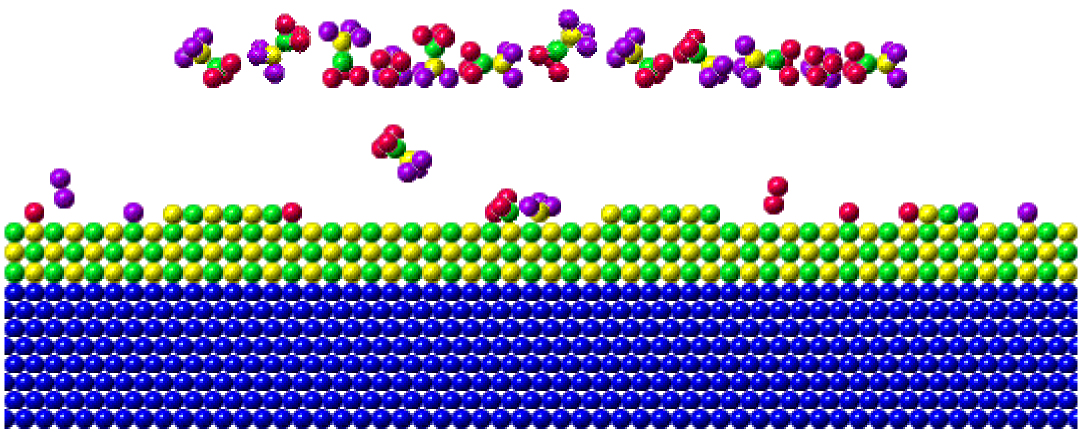


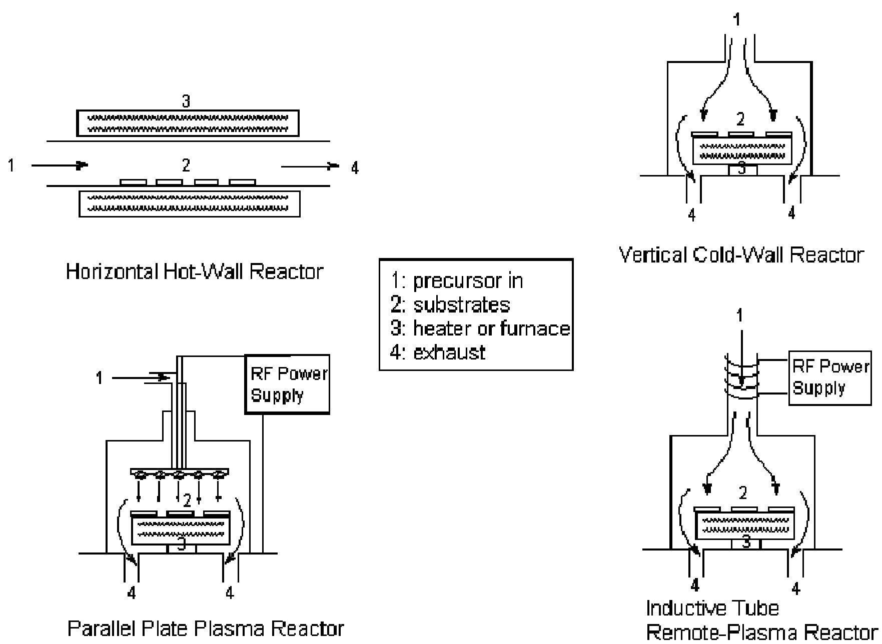
Figure courtesy of Hsin-Tien Chiu.

Over time the gas deposits also bond to the sides of the chambers. They can become thick enough to cause particle problems on the wafer surface. Some companies will clean the chamber after thousands of passes of wafers. Other companies have continuous monitoring equipment to tell more precisely when cleaning is necessary. This equipment includes Fourier Transform Infrared Spectroscopy (FTIR) machinery which is designed to measure numerous chemicals exiting the chamber for one instant of time. The counterpart to FTIR machinery is the Quadrapole Mass Spectrometer, which is designed to measure flow rates of major chemicals.

Process tools vary significantly in design. Some tools have only one CVD chamber with one wafer to be layered at a time. Other tools can layer three or more wafers at a time. Still other tools have multiple chambers of which one is for layering. The number of layers required is determined by the product recipe and ranges from one to more than twenty layers per wafer.

The fluorinated gas most widely used to clean CVD chamber walls is C_2F_6. However, this gas does not have a high utilization efficiency such that up to 70 percent of the input gas may be emitted (SEMATECH, 2005). With the use of alternative chemistries there has been an increase in the removal rate of chamber debris per pound of gas used. Some of the alternative chemistries, such as NF_3, are so aggressive in the removal of materials that the chamber walls may be damaged. Therefore new tools with specially designed chamber walls may be required. Figure III-3 shows various CVD chambers and how the precursors move near the chamber walls.

Figure III-3
Gas Movement by CVD Chamber Walls



Note: The abbreviation “RF” in Figure III-3 refers to Radio Frequency power sources.

Figure courtesy of Hsin-Tien Chiu.

C. ETCHING

Etching is a chemical reactive process for selectively removing material deposited on a wafer during manufacturing. The purpose of this removal is to fill the trenches with metal that will form the wires that connect components. Etching includes wet etching with liquid chemicals, such as buffered hydrofluoric acid, or dry etching (plasma etching) with fluorinated, ionized gases. Etchants include, but are not limited to, CF_4, CHF_3, C_2F_6, C_3F_8, c-C_4F_8, NF_3, and SF_6 (U.S. EPA, 2001).

Etching removes materials at a finer thickness than three micrometers, which is the limit for wet etching. Plasma etching allows the creation of a feature size, meaning the minimum width of a pattern such as used in defining a transistor, of less than $1/100^{th}$ the width of a human hair. This requires the atoms in the plasma etchant to have the right ratio of oxygen, hydrogen, carbon and fluorine and is achieved by adding the right amount of oxygen with fluorinated gases such as CF_4, c-C_4F_8, CHF_3, SF_6 and others (Glade, 2008).

Occasionally fluorinated gases are used to clean the etch chamber, however, this is not done as frequently as for CVD chamber cleaning because much lower volumes of gases are used in etching.

Figure III-4
Etch Tool

Figure courtesy of March Plasma Systems.

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IV. EMISSIONS

California's extreme air quality problems require unique strategies for improving air quality and slowing global warming. This chapter provides an overview of climate change and its predicted impacts. This chapter also presents GHG emissions estimates for the semiconductor industry based on ARB survey results, and the estimated emission benefits from the proposed rulemaking.

A. CLIMATE CHANGE

Climate change, or global warming, is the process whereby emissions of anthropogenic pollutants, together with other naturally-occurring gases, absorb infrared radiation in the atmosphere, leading to increases in the overall average global temperature. While carbon dioxide (CO_2) is the largest contributor to radiative forcing, methane, halocarbon, nitrous oxide (N_2O) and other species also contribute to climate change. Gases in the atmosphere can contribute to the greenhouse effect both directly and indirectly. Direct effects occur when the gas itself is a GHG. The standard definition of a GHG includes, but is not limited to, six substances as identified in the Kyoto Protocol and AB 32; CO_2, methane (CH_4), N_2O, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Nitrogen trifluoride (NF_3), while not a Kyoto gas, is included in the proposed regulation as a GHG.

While there is relative agreement on how to account for direct effects of GHG emissions, accounting for indirect effects is more problematic. Indirect radiative forcing occurs when chemical transformations of the original gas produce other GHGs, when a gas influences the atmospheric lifetimes of CH_4, and/or when a gas affects atmospheric processes that alter the radiative balance of the earth (e.g. affect cloud formation) (ARB, 2008).

High global warming potential (GWP) gases are a unique challenge in that just a few pounds of high GWP materials can have the equivalent effect on global warming as several tons of carbon dioxide. GHG emissions from semiconductor operations are small relative to other sources such as vehicle exhaust, however, some of the most potent gases are used in this industry. The magnitude of the climate change problem justifies reductions from smaller sources wherever such regulations are technically feasible and cost-effective.

Controlling multiple substances that jointly contribute to climate warming requires some method to compare the effects of the different gases because the physical properties (climate warming impact and persistence in the atmosphere) of the GHGs are very different. The current solution to this problem is the calculation made by the IPCC (IPCC, 2006). The basic idea is to calculate the cumulative climate warming over a specified time span resulting from one unit mass of the GHG emitted. The estimates of GWPs have been extensively reviewed by many climate scientists around the world. The IPCC is constantly evaluating GWP values and the assessment is generally updated every six years.

By convention, the GWP index is defined relative to CO_2 which has a GWP of one. The IPCC defines the GWP of a GHG as the ratio of the time-integrated radiative forcing impact from an instantaneous release of 1 kilogram (kg) of a trace substance relative to that of 1 kg of CO_2. The standard unit of measurement used to express the emissions of a GHG is MMT CO_2e per year. The GWP values used by staff were the IPCC Second Assessment Report (SAR) GWP values (ARB, 2007a). The values, shown in Table IV-1, are used when converting emissions of fluorinated gases to CO_2e. The GWP values from the SAR as opposed to the IPCC Fourth Assessment Report were used for all fluorinated gases except NF_3 to maintain consistency with the Board's Discrete Early Action Report, other statewide and national GHG inventories, and the Scoping Plan.

Table IV-1
IPCC GWP Values

Fluorinated Gas	Second Assessment 100-Year Values
C_2F_6	9,200
C_3F_8	7,000
CF_4	6,500
CHF_3	11,700
$c\text{-}C_4F_8$	8,700
NF_3	17,200*
SF_6	23,900

*Used IPCC Fourth Assessment 100-Year GWP value because no Second Assessment 100-Year GWP value is available.

The proposed regulation to reduce emissions of fluorinated gases from semiconductor operations will have an overall beneficial impact on climate change. The adoption of this proposed regulation will result in an estimated reduction of 0.18 MMT CO_2e per year (ARB, 2007b).

B. PREDICTED CLIMATE CHANGE IMPACTS

Global average temperatures have risen both on land and in the oceans, with observable impacts already occurring. Scientists predict that if the increase in GHG emissions continues unabated, temperatures will rise by as much as 10 degrees Fahrenheit by the end of this century (ARB, 2008). It is impossible to predict exactly how climate change will affect California's ecosystems and economy in the future. However, the expected physical changes will impact California's public health, economy and ecology.

One area of considerable concern is the effect of climate change on California's water supply. During the winter, in our mountains, snow accumulates in a deep pack, preserving much of California's water supply. If winter temperatures are warmer, however, more precipitation will fall as rain, decreasing the size of the snow pack. Heavier rainfall in the winter could bring increased flooding. Less spring runoff from a smaller snow pack will reduce the amount of water available for hydroelectric power production and agricultural irrigation. Evidence of this problem already exists. Throughout the 20th century, annual April to July spring runoff in the Sierra Nevada has been decreasing, with water runoff declining by about ten percent over the last 100 years.

Another predicted outcome of climate change is a rise in sea level. California has already experienced a 3 to 8 inch rise in sea level in the last century. If the trend continues, large populations living along California's coast will face serious consequences such as flooding of low-lying property, loss of coastal wetlands, erosion of cliffs and beaches, saltwater contamination of drinking water, and damage to roads and bridges.

Air pollution will also be exacerbated by increasing temperatures. Higher temperatures, strong sunlight, and stable air masses could lead to increased concentrations of ground-level ozone.

Climate change could impact California agriculture by increasing demand for irrigation to meet higher evaporative demand, while supply will become less reliable due to declining snow pack in the mountains. Climate change will also put our forests at greater risk for fire and disease (ARB, 2008).

C. SEMICONDUCTOR INDUSTRY EMISSIONS SURVEY RESULTS

Originally, the emissions inventory estimate for the semiconductor industry in California was 0.88 MMT CO_2e for the 2004 calendar year (U.S. EPA, 2007a). This was based on U.S. EPA national emissions data (U.S. EPA, 2007b) and U.S. Census Bureau shipment figures (U.S. Census, 2002). After discussions with the industry and other interested parties, ARB staff determined that the emissions inventory overestimated the GHG emissions from semiconductor operations. To refine the emissions estimate for the semiconductor industry, ARB staff conducted a survey of California's semiconductor operations (ARB, 2007c).

The survey collected 2006 data from semiconductor manufacturers, research and development organizations, tool manufacturers, and universities. The survey was developed with the participation of semiconductor manufacturers and members of the SIA, air district staff, U.S. EPA staff and other interested parties. The mailing list was derived from the ARB's emissions inventory and the air districts' databases. The survey provided ARB staff with the following information:

- types and amounts of fluorinated gases used;
- sizes and quantities of wafers produced or processed;
- business information on employees to identify small businesses;
- operation types;
- process optimization and alternative chemistries used;
- emissions abatement technologies used;
- information needed to calculate emissions; and
- other strategies used to reduce fluorinated gas emissions.

The survey was sent to over 300 semiconductor operations statewide and over ninety percent responded to the survey. A copy of the survey is contained in Appendix B.

The proposed regulation was based on the survey results, technical information provided by interested parties and staff's research efforts. During the workgroup meetings and public workshops, staff presented specific proposals and alternatives for consideration. Staff modified the original proposal after considering comments offered.

Eighty-five operations were identified as semiconductor operations in California that are subject to the proposed regulation. Table IV-2 contains a summary of respondent statistics.

Table IV-2
Summary of Survey Respondents

Number of operations surveyed	308
Number of operations that responded	302
Number of operations using fluorinated gases in California	85

To protect confidentiality, ARB staff posted to ARB's webpage a summary detailing fluorinated gas usage in aggregate form and provided estimated emissions for the semiconductor industry. The preliminary results were discussed at a public workshop and input from industry was used to correct any inaccuracies in the data. The survey data provide a sound basis for developing the proposed regulation and estimating emissions.

The number of semiconductor operations by size category and district is shown in Table IV-3.

Table IV-3
2006 Semiconductor Operations by District

Size Category	Total Operations	Bay Area	South Coast	Ventura	Santa Barbara	Sacramento	Placer
Tier 1: >37.7 Million Sq Cm Per Year	5	2	2	0	0	0	1
Tier 2: >3.7 and ≤37.7 Million Sq Cm Per Year	11	8	1	2	0	0	0
Tier 3: ≤3.7 Million Sq Cm Per Year	12	9	3	0	0	0	0
Reporting Only*	57	38	11	3	3	2	0
Total Operations	**85**	**57**	**17**	**5**	**3**	**2**	**1**
% of Total Operations		67	20	6	4	2	1

Note: * Emission threshold for Reporting Only operations is 0.0008 MMT CO2e. Reporting Only operations include tool manufacturers, R&D, and other small operations.

D. SEMICONDUCTOR INDUSTRY EMISSIONS

This section discusses the emission estimates from the proposed rulemaking for the semiconductor industry. The emissions in MMT CO_2e for a fluorinated gas are determined by multiplying the emissions calculated using the IPCC Tier 2b methodology by the GWP value for that gas and dividing by one billion, or the number of kilograms in one MMT. Emission factors and destruction efficiency values are based on the IPCC 2006 report (IPCC, 2006).

Table IV-4 shows the volume of fluorinated gas used and CO_2e emissions by process for each gas. Fifty percent of total emissions are attributed to C_2F_6, the predominant gas used in CVD chamber cleaning.

Table IV-4
2006 Fluorinated Gas Use and Emissions

Fluorinated Gas	Use in Etch Process (Kg)	Use in CVD Chamber (Kg)	Etch Emissions (MMT CO_2e)	CVD Chamber Emissions (MMT CO_2e)	Percent of Total Emissions
C_2F_6	7,270	28,700	0.03	0.13	50
C_3F_8	1,280	7,500	0.007	0.02	8
CF_4	13,100	1,270	0.05	0.004	17
CHF_3	4,080	90	0.01	0.0008	4
c-C_4F_8	980	4,320	0.003	0.007	3
NF_3	4,480	15,090	0.01	0.006	5
SF_6	9,110	155	0.04	0.003	13
Total	**40,300**	**57,125**	**0.15**	**0.17**	**100**

Table IV-5 shows the proposed emission standards, number of potentially impacted operations, and emission estimates.

Table IV-5
Proposed Emission Standards for Semiconductor Operations
Effective 1/1/2012

Category (Million Sq Cm Per Calendar Yr)	Maximum Emissions Limit Per Square Centimeter for a Calendar Year (Kg CO_2e/cm^2)	Number of Operations	2006 Emissions (MMT CO_2e)
Tier 1: >37.7	0.2	4*	0.17
Tier 2: >3.7 and ≤37.7	0.3	8*	0.08
Tier 3: ≤3.7	0.5	12	0.05
Reporting Only	NA	NA**	0.02
Total	**NA**	**24**	**0.32**

* From the survey, we were informed that one business in Tier 1 (already is in compliance) and three businesses in Tier 2 were planning on ceasing operation before the emission standards were proposed.
** Reporting Only operations (57) are not subject to the proposed emission standards.

The emission standards, expressed in kilograms of carbon dioxide equivalent (Kg CO_2e) per square centimeter of wafer processed, are based on the quantity of wafers processed at the semiconductor operation in a calendar year. As Table IV-5 shows, an owner or operator of a semiconductor operation must meet the emission standards by January 1, 2012. The Tier 1 emission standard applies to an owner or operator of any size semiconductor operation that begins operation after January 1, 2010, and emits more than 0.0008 MMT CO_2e per year. Owners or operators that replace certain processing equipment with newer equipment are allowed an additional two years, until January 1, 2014, to comply with the standards. The provision will encourage early emission reductions to occur as newer process tools are more efficient and have greater longevity.

Semiconductor operations that emit 0.0008 MMT CO_2e or less per reporting calendar year are not subject to the emissions standards in Table IV-5, but are subject to the annual reporting and recordkeeping requirements. Staff considered further emission reductions from these 57 operations, referred to as "reporting only," as not cost-effective. Collectively they represent only 6 percent of the total emissions.

Under the current proposal and based on the 2006 survey results, 24 semiconductor operations would be subject to emission standards and reporting and recordkeeping requirements. Fifty-seven operations would be subject to reporting and recordkeeping requirements only. All owners or operators would be required to submit an emissions report annually for the emissions occurring in the previous calendar year.

REFERENCES

1. Air Resources Board. ARB Compendium of Emission Factors and Methods to Support Mandatory Reporting of Greenhouse Gas Emissions, Appendix A. October 2007. (ARB, 2007a)

2. Air Resources Board. Initial Statement of Reasons for Proposed Amendments to the California Consumer Products Regulation. May 9, 2008. (ARB, 2008)

3. Air Resources Board. Expanded List of Early Action Measures to Reduce Greenhouse Gas Emissions in California Recommended for Board Consideration. October 2007. (ARB, 2007b)

4. Air Resources Board. Semiconductor Emissions Survey. December 14, 2007. (ARB, 2007c)

5. Intergovernmental Panel on Climate Change. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 3, Chapter 6. (IPCC, 2006)

6. United States Environmental Protection Agency. Fast Facts (April 2007), Office of Atmospheric Programs, U.S. GHG Emissions Inventory (PDF, 2pp.) EPA 430-F-07-004. Online Internet at http://epa.gov/climatechange/emissions/downloads/2007GHGFastFacts.pdf. (U.S. EPA, 2007b)

7. United States Environmental Protection Agency. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005. April 15, 2007. (U.S. EPA, 2007a)

8. United States Census Bureau. U.S. Census Bureau's Economic Census, http://www.census.gov/econ/census02/ (for value of semiconductor shipments produced at the state and national levels.) Information is listed by NAICS Code Number. The NAICS Code for "Semiconductor Manufacturing = #334413" (U.S. Census, 2002)

V. DEVELOPMENT OF PROPOSED REGULATION

In this chapter, staff provides a "plain English" discussion of key requirements of the proposed regulation to reduce emissions of fluorinated GHGs from semiconductor operations. This chapter begins by presenting the public outreach efforts used in developing the regulation, then summarizes the proposed regulation and concludes by describing each major requirement and compliance option. A copy of the proposed regulation is available in Appendix A of this report.

A. PUBLIC OUTREACH

The Administrative Procedures Act (Government Code section 11340 *et seq*.) requires public input during rulemaking development. Staff has made extensive efforts to provide opportunities for participation in the rulemaking process. Staff's public outreach efforts included participation from members of SIA, semiconductor manufacturers, process tool manufacturers, fluorinated gas suppliers, air district staff, U.S. EPA staff, public health representatives, environmental and pollution prevention association representatives and other interested parties.

Staff's outreach activities included the following:

- Provided a draft survey to the SIA and select manufacturers for review and comment;
- Conducted a survey of California's semiconductor operations;
- Held working group meetings;
- Held four public workshops;
- Made extensive personal contacts with industry representatives, and other interested parties through meetings, telephone calls, and mail- outs;
- Formed an ARB/Industry Working Group and conducted three conference calls with group members;
- Formed an ARB/District Working Group and conducted conference calls with group members;
- Created a website and maintained an email address list to automatically update interested parties about rulemaking developments;
- Mailed workshop notices and posted workshop materials on the website; and
- Conducted site visits to three semiconductor operations.

Air districts' staff were also actively involved in the rulemaking development process. Staff from the air districts provided comments on the draft regulatory language and information on permitting requirements for the semiconductor operations within their jurisdiction.

B. SUMMARY OF PROPOSED REGULATION

The proposed regulation applies to semiconductor operations in California that use fluorinated GHGs in CVD chamber cleaning or etching processes. The proposed emission standards only apply to semiconductor operations in California that emit more than 0.0008 MMT CO_2e per calendar year. These 28 sources account for 94 percent of the emissions from semiconductor operations. The proposed emission standards do not apply to semiconductor operations that emit 0.0008 MMT CO_2e or less per year because they constitute only six percent of the emissions and it would not be cost-effective to regulate these small businesses, primarily research and development operations.

Reporting and recordkeeping requirements apply to all operations, including those emitting less than or equal to 0.0008 MMT CO_2e per year. Owners and operators must comply with emission standards effective January 1, 2012. All owners and operators subject to the regulation are required to keep records of semiconductor operations and submit an initial report and annual reports thereafter to the air districts.

Owners or operators of semiconductor operations generally would be required to comply with the emission standards by January 1, 2012. However, an operation replacing 150 millimeter (mm) wafer processing tools with 200 mm or greater tools would have until January 1, 2014 to comply with the emission standards. Providing more time for sources that are upgrading their wafer processing tools to comply with emission standards encourages early GHG reductions that are achievable with more efficient 200 mm tools. The additional time also avoids the costly situation of installing abatement devices on old processing tools just before they are scheduled to be replaced. All semiconductor operations would be subject to the same timeframe for reporting and recordkeeping requirements.

The emission standards for semiconductor operations are tiered, and vary depending upon the quantity of wafers (thin semiconductor material from which integrated circuits or "chips" are made) processed at a facility. The quantity of wafers processed is measured in square centimeters, and includes all wafers processed at a facility, including those that do not pass inspection.

We are proposing that seven sections be added to title 17, Subchapter 10, Article 4, Subarticle 2 of the California Code of Regulations. These are:
section 95320 "Purpose," section 95321 "Applicability,"
section 95322 "Definitions," section 95323 "Standards for a Semiconductor Operation," section 95324 "Reporting Requirements," section 95325 "Recordkeeping Requirements," and section 95326 "Severability."

1. PURPOSE (Section 95320)

The purpose of this regulation is to reduce fluorinated gas emissions from semiconductor operations pursuant to the California Global Warming Solutions Act of 2006.

2. APPLICABILITY (Section 95321)

This regulation applies to semiconductor operations using fluorinated gases in their etching and chemical vapor deposition (CVD) chamber cleaning processes. It also requires reporting on the use of fluorinated heat transfer fluids. Semiconductors and related devices include, but are not limited to, diodes, zeners, stacks, rectifiers, integrated microcircuits, transistors, solar cells, light-sensing devices, and light-emitting devices.

The proposed emission standards apply only to semiconductor operations in California that emit more than 0.0008 MMT CO_2e per calendar year, although reporting and recordkeeping provisions apply to all operations regardless of emissions levels. Owners and operators of semiconductor operations must comply with emission standards effective January 1, 2012, except those operations replacing 150 millimeter (mm) wafer processing tools with 200 mm or larger tools. Those operations would have until January 1, 2014 to comply with the proposed standards. The time extension recognizes the value of voluntary efforts that would reduce emissions, avoids penalizing these operations by requiring emission control technology on older and short-lived tools, and encourages operations to consider process tool upgrades.

3. DEFINITIONS (Section 95322)

To ensure common understanding and improve enforceability of the regulation, this section provides all the terms used in the proposed semiconductor regulation which are not self-explanatory. The definition of fluorinated gases required clarification as the term has various meanings depending upon the source.

Some of the fluorinated gases include, but are not limited to:

- hexafluoroethane (C_2F_6);
- octafluoropropane (C_3F_8);
- octafluorocyclopentene (C_5F_8);
- tetrafluoromethane (CF_4);
- trifluoromethane (CHF_3);
- difluoromethane (CH_2F_2);
- octafluorocyclobutane ($c\text{-}C_4F_8$);
- octafluorotetrahydrofuran (C_4F_8O);
- hexafluoro-1,3-butadiene (C_4F_6);
- carbon fluoride oxide (COF_2);
- nitrogen trifluoride (NF_3); and
- sulfur hexafluoride (SF_6).

4. STANDARDS (Section 95323)

The emission standards for semiconductor operations are tiered, and vary depending upon the quantity of wafers (thin semiconductor material from which integrated circuits or “chips” are made) processed at a facility. The quantity of wafers processed is measured in square centimeters of the surface area of one side of the wafer, and includes all wafers processed at a facility, including those that do not pass inspection.

The emission standards in this regulation, expressed in kilograms of carbon dioxide equivalent (kg CO_2e) per square centimeter of wafer processed, are based on the quantity of wafers in square centimeters processed at a facility in a year, and are grouped into three tiers as follows:

Tier 1: Up to 0.2 kg CO_2e per square centimeter of wafer processed may be emitted by operations processing greater than 37.7 million square centimeters of wafers in a calendar year.

Tier 2: Up to 0.3 kg CO_2e per square centimeter of wafer processed may be emitted by operations processing greater than 3.7 and less than or equal to 37.7 million square centimeters of wafers in a calendar year, provided operations were in existence prior to January 1, 2010.

Tier 3: Up to 0.5 kg CO_2e per square centimeter of wafer processed may be emitted by operations processing less than or equal to 3.7 million square centimeters of wafers in a calendar year, provided operations were in existence prior to January 1, 2010.

All semiconductor operations established on or after January 1, 2010, regardless of square centimeters of wafers processed, would be required to meet the Tier 1 standard if they emit more than 0.0008 MMT CO_2e per year.

The proposed standards shown in Table V-1, achieve the maximum technologically feasible emission reduction based on information obtained in ARB's 2006 survey of semiconductor operations and discussions with semiconductor manufacturers, and manufacturers of fluorinated gas emission control devices.

Table V-1
Emission Standards for Semiconductor Operations
Effective January 1, 2012

CVD Chamber Cleaning and Etching Processes	
Wafer Surface Area Processed (Million Square Centimeters Per Calendar Year)	**Maximum Emissions Limit Per Square Centimeter for a Calendar Year ($Kg\ CO_2e/cm^2$)**
Tier 1: >37.7	0.2
Tier 2: >3.7 and ≤ 37.7	0.3
Tier 3: ≤3.7	0.5

The proposed emission standards do not apply to those semiconductor operations that emit 0.0008 MMT CO_2e or less per calendar year. Based on ARB's survey results, 57 semiconductor operations that emit 0.0008 MMT CO_2e or less per year account for six percent of the GHG emissions. Twenty-seven of these operations are small businesses, and all 57 operations account for only three percent of fluorinated gas usage. Our analysis indicates that the minor emission reductions achievable by subjecting these research and development operations to the emission standards are not cost-effective. Consequently, we are proposing to cap their emissions at the 0.0008 MMT CO_2e threshold level and subject them to annual reporting and recordkeeping requirements.

5. REPORTING REQUIREMENTS (Section 95324)

Emissions reporting requirements include both initial and annual reporting. For the initial report, due to the permitting agency no later than March 1, 2011, semiconductor operations must report fluorinated gas emissions from January 1, 2010 through December 31, 2010. For annual emissions reports, due to the permitting agency beginning March 1, 2012 and each year thereafter, semiconductor operations must report for the previous calendar year.

In addition to emissions of fluorinated gases, the annual emissions report will contain information on:

- the amounts of fluorinated gases used in CVD chamber cleaning and etching operations;
- the amount of semiconductor wafers processed for operations emitting more than 0.0008 MMT CO_2e per year;
- the use of process optimization, alternative chemistries, or equipment used to reduce fluorinated gas emissions; and
- information regarding the use of fluorinated heat transfer fluids.

6. RECORDKEEPING REQUIREMENTS (Section 95325)

Recordkeeping requirements would mandate that the owner or operator maintain records on quantities of fluorinated gases and heat transfer fluids purchased or delivered, as well as records of emission control equipment malfunctions and failures. All records must be maintained at an operation and be readily accessible for inspection for at least three years.

7. SEVERABILITY (Section 95326)

The proposed regulation contains a severability clause stipulating that in the event any portion of the proposed regulation is deemed invalid, the remainder of the proposed regulation will continue in full force and effect.

C. COMPLIANCE WITH THE PROPOSED REGULATION

At present there are many semiconductor operations that comply with the proposal using process optimization, alternative chemistries and control devices that minimize GHG emissions. For several years, some manufacturers in California voluntarily reduced GHG emissions by way of agreements with the U.S. EPA and the World Semiconductor Council. In fact, this proposed regulation will be the first time this industry will be required by law to comply with GHG regulations specific to their industry. While we do not wish to negate the voluntary efforts by the industry to reduce GHG emissions, the proposed regulation will ensure that all semiconductor operations in California reduce GHG emissions to the maximum extent that is technically and economically feasible.

Owners and operators of semiconductor operations have the flexibility of choosing how they will comply with the proposed regulation. They may elect to use process optimization, alternative chemistries, or abatement technologies, in combination or separately, to reduce GHG emissions. Twelve of the 24 operations in Tiers 1, 2, and 3 that responded to the ARB survey already comply with the proposed standards. Table V-2 shows the option(s) currently used by complying operations.

Each tier contains operations that process wafers of varying complexity. Because the volume of gas usage increases with wafer complexity, the operations processing more complex wafers may need to use all three compliance strategies to meet the proposed standards. For example, the complying Tier 1 operation with more complex wafer designs, i.e., a higher average number of layers, uses all three emission reduction options. Those with less complex wafer designs are able to meet the standards with fewer compliance strategies. In some cases, operations may comply without using any of the control strategies.

Table V-2
Compliance Strategies for Complying Operations

Category	Operation	Process Optimization		Alternative Chemistries	Abatement		Remote Plasma
		Use in Etching	Use in CVD Chamber		Use in Etching	Use in CVD Chamber	
Tier 1	1	---	---	---	---	---	---
	2	X	X	X	X	X	X
Tier 2	1	X	X	X	X	X	---
	2	---	---	---	---	---	---
	3	---	---	---	---	---	---
	4	X	X	---	---	---	---
	5	---	X	---	---	---	X
Tier 3	1	X	---	---	---	---	---
	2	---	---	---	---	---	---
	3	X	---	---	---	---	---
	4	X	X	---	---	---	---
	5	---	---	---	---	---	---

Table V-3 shows emissions, emission reductions, and complying market shares. This Table shows complying Tier 1 operations represent 57 percent of the Tier 1 market. The complying market shares for Tiers 2 and 3 are 43 and 34 percent, respectively.

Table V-3
2006 Emissions and Emission Reductions
CVD Chamber Cleaning and Etching Processes

Category	Number of Operations	Emissions (MMT CO_2e)	Percent Complying Market Share	Emission Reductions (MMT CO_2e)
Tier 1	5	0.17	57	0.11
Tier 2	11	0.08	43	0.03
Tier 3	12	0.05	34	0.04
Reporting Only	57	0.02	NA	NA
Total	**85**	**0.32**	**NA**	**0.18**

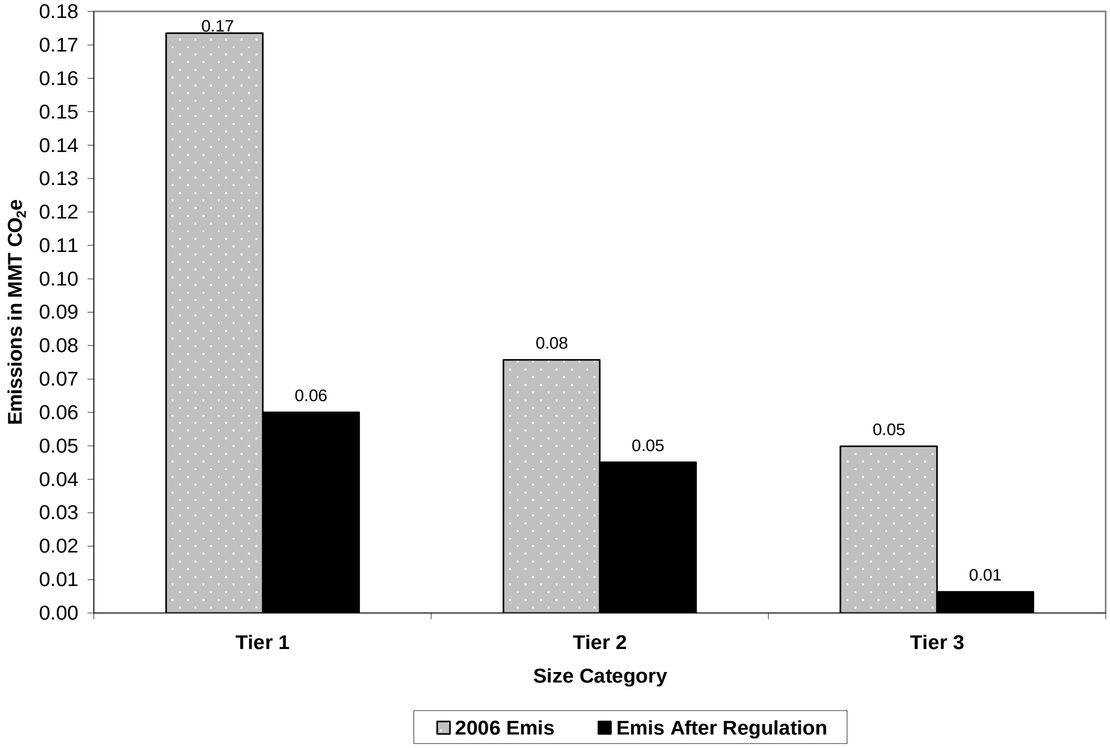
The percent complying market share is tier specific and is simply the wafer production currently complying with the emission standard compared to total wafer production for that tier. Based on the technical feasibility demonstrated through the complying market share and the range of compliance options, staff believes the proposed limits are feasible.

Figure V-1 shows by Tier the 2006 calendar year emissions and the remaining emissions after the proposed regulation becomes effective. Estimated emission reductions for Tier 1 are 0.11 MMT CO_2e per year. Tier 2 and 3 reductions are estimated at 0.03 and 0.04 MMT CO_2e per year, respectively. While Tier 1 operations account for 61 percent of the total emission reduction, Tier 3 operations will achieve the greatest percentage reduction from current practices. This is because these smaller operations have not voluntarily reduced emissions by using emission control options.

1. PROCESS OPTIMIZATION

Process optimization reduces the volume of fluorinated gas used in CVD chamber cleaning to the optimal volume and is achieved by using either a Quadrapole Mass Spectrometer (Q-mas) system or a Fourier Transform Infrared Spectroscopy (FTIR) unit. These devices sample the chemical constituents of the effluent to determine precisely when there are no more residual chemicals flowing through the processing chamber. Process optimization reduces gas consumption thereby reducing operating costs. For example, the International Sematech Manufacturing Initiative report estimates that process optimization for C_2F_6 usage reduces CVD chamber cleaning emissions by 10 to 56 percent (SEMATECH, 2005). Process optimization is the lowest cost emission reduction strategy. It is particularly useful for older fabs that may be using more process gas than necessary.

Figure V-1
Emissions Before and After Proposed Regulation



2. ALTERNATIVE CHEMISTRIES

Alternative chemistry is the substitution of one gas for another to achieve a net environmental benefit. For example, a higher GWP gas can be used to replace a lower GWP gas if the replacement gas is used more efficiently, thereby resulting in a net environmental benefit. Initially, C_2F_6 was the only chemical used by the semiconductor industry for CVD chamber cleaning. More recently, C_3F_8, c-C_4F_8, C_4F_8O and NF_3 have all been found to be possible alternatives. The first three alternatives (C_3F_8, c-C_4F_8, and C_4F_8O) are "drop-in" replacements for C_2F_6, while NF_3 requires new machinery because of the aggressive nature of the gas. Two complying operations in the tier groupings cite the use of alternative chemistry and have replaced C_2F_6 in either CVD chamber cleaning or etch processes.

When a semiconductor operator considers using an alternative chemistry a number of factors are evaluated. An operator needs to evaluate if the change in chemistry would produce any detrimental effects on tool and film properties, including uniformity, number of defects, and the chip performance. Usually the process of evaluating all of these factors before making the change takes six months to a year. There may also be an initial one to two week downtime for a tool when the change in chemistry is implemented.

Once the decision is made to use an alternative chemistry, only one gas is selected for a given tool. Combinations, such as C_3F_8 and c-C_4F_8, are not used. Alternative chemistries can be used in CVD chamber cleaning or etching.

Table V-4 provides a summary comparison by type of gas for alternative chemistries to replace C_2F_6 in CVD chamber cleaning (SEMATCH 2005).

Table V-4
Alternative Chemistries Summary

C_2F_6 Replacement Chemistry	Utilization Efficiency* (%)	Emissions Reduction from Baseline C_2F_6 Process (%)
C_3F_8	30–60	12–70
c-C_4F_8	70–90	50–85
C_4F_8O	85–90	70–90
NF_3	60–80	20–90

* Utilization efficiency is the percentage of the gas used in the process. A 30 percent utilization efficiency means that 70 percent of the gas is emitted.

3. ABATEMENT

The remaining option to reduce the emissions from semiconductor operations is to abate the emissions before they are released into the atmosphere. The two primary methods of abating high GWP gases from the exhaust streams are: 1) thermal destruction; and 2) plasma destruction. Thermal destruction devices may be applied at a single tool, called point–of–use (POU) abatement, or at the end of several tools, which is called end–of–pipe abatement. The advantage of POU devices is a lesser tendency to have build-up of chemicals in the tubes carrying the effluent to the device. The disadvantage is that the POU devices mitigate the effluent from only one tool.

There are three main types of POU abatement systems:
1) fuel burner–scrubbers; 2) electric heated–scrubbers; and 3) pre-pump plasma units. In each case the exhaust gas is heated to high enough temperatures to "crack" off the fluorine atom from the strong carbon-to-fluorine or fluorine-to-fluorine bond. Toxic hydrofluoric acid (HF) is formed in the process, but can be removed with a water scrubber. The three types of abatement systems differ in how they heat the gas to the high temperatures needed to destroy emissions. The fuel burner–scrubber combusts propane, methane, natural gas or a hydrogen

flame to reach the temperatures needed. The electric heated–scrubber uses an electrically heated mesh of steel that often is white hot. The pre-pump plasma unit uses an inlet of plasma.

Based on our survey, most of the operations in California that use thermal destruction use POU fuel burner–scrubbers. The majority of these operations apply the technology to CVD chamber cleaning, with all three tiers having at least one operation represented. However, several operations also abate etching tool effluents, although this does not occur across all three tiers. Electric heated–scrubbers are also used in both processes, but were fewer in number.

Ten operations cited the use of remote plasma to abate fluorinated gas emissions. Remote plasma is used by operations in Tiers 1 and 2 and in the reporting only category.

There are other abatement technologies that are used less frequently. This includes one operation in the reporting only category that uses catalytic–scrubbers and pre-pump plasma to treat etching gases. Another operation in the same category uses only pre-pump plasma to treat etching gases. One operation uses only catalytic–scrubbers to treat etching and CVD gases and one operation uses end–of–pipe abatement for CVD chamber cleaning emissions. This operation also uses POU-type abatement for some etch tools.

Before operators purchase abatement devices, they need to consider the maximum downtime allowable to make the change, the cost of ownership, and the minimum Destruction Removal Efficiency (DRE) of the device.

D. EVALUATION OF REGULATORY ALTERNATIVES

California Government Code section 11346.2 requires ARB to consider and evaluate reasonable alternatives to the proposed regulation and provide reasons for rejecting those alternatives. This section discusses the alternatives evaluated and provides the reasons why they were not included in the proposed rulemaking. Staff evaluated each of the alternatives and determined that the alternatives did not meet the objective of Health and Safety Code section 38560 to achieve the maximum technologically feasible and cost-effective greenhouse gas emission reductions in furtherance of achieving the statewide GHG emissions limit.

- **No Action -** A “no action” alternative would forego or delay the adoption of the proposed rulemaking. This alternative was rejected as it would result in failure to make progress in reducing emissions of high GWP GHGs from semiconductor operations.

- **Alternative Standards -** The alternative standards option is to impose a different standard on etching processes and CVD chamber cleaning processes. This alternative sets separate emissions limits for CVD chamber cleaning and etching based on the lowest emitting operations for each process within each tier. The total emission reduction would increase from 0.18 to 0.22 $MMTCO_2e$. Since this alternative would impact more businesses than the current proposal, the annual cost was estimated to be $6.3 million. This option also increases the complexity of the regulation. Industry expressed concern that process specific emission standards would not be technically feasible and would not provide sufficient compliance flexibility. Staff concurs and, therefore, rejected this alternative.

E. ALTERNATIVE MEANS OF COMPLIANCE

The proposed regulation allows for flexibility in methods of compliance. Rather than specify a compliance mechanism, operators may choose compliance method(s) best suited to their needs. Process optimization, alternative chemistries, and abatement technologies are among the compliance options available. Operators may choose to implement any or all of these compliance options to meet the proposed emission standards.

ARB staff has concluded that the proposed regulation provides the most effective and least burdensome approach to reducing GHG emissions from semiconductor and related devices operations. The proposed regulation provides operators with flexibility while preserving the emission benefits.

REFERENCES

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VI. ENVIRONMENTAL IMPACTS

A. INTRODUCTION

The goal of this regulation is to reduce emissions of greenhouse gases from semiconductor operations. An additional consideration is the impact that the proposed regulation may have on the environment. This chapter describes the potential impacts that the proposed regulation may have on air quality, water treatment, and hazardous waste disposal. Based upon available information, we determined that no significant adverse environmental impacts should occur as a result of adopting the proposed regulation.

B. LEGAL REQUIREMENTS APPLICABLE TO THE ANALYSIS

The California Environmental Quality Act (CEQA) and ARB policy require an analysis to determine the potential environmental impacts of proposed regulations. ARB's program for adopting regulations has been certified by the Secretary of Resources, pursuant to Public Resources Code section 21080.5. Consequently, the CEQA environmental analysis requirements may be included in the Initial Statement of Reasons (ISOR) for this regulation. In the ISOR, the ARB must include a functionally equivalent document, rather than adhering to the format described in CEQA of an Initial Study, a Negative Declaration, and an Environmental Impact Report. In addition, staff will respond to all significant environmental issues raised by the public during the 45 day public review period or at the Board hearing in the Final Statement of Reasons for the proposed regulation.

Public Resources Code section 21159 requires that the environmental impact analysis conducted by ARB include the following:

- An analysis of reasonably foreseeable environmental impacts of the methods of compliance;
- An analysis of reasonably foreseeable feasible mitigation measures; and
- An analysis of reasonably foreseeable alternative means of compliance with the proposed regulation.

Compliance with the proposed regulation is expected to directly affect air quality and potentially affect other environmental media as well. Our analysis of the reasonably foreseeable environmental impacts of the methods of compliance is presented in sections C and D.

C. POTENTIAL ENVIRONMENTAL IMPACTS

As previously mentioned, there are several compliance options manufacturers may use to control GHG emissions from semiconductor operations. Each of these options and any potential environmental impacts are discussed in this section.

1. PROCESS OPTIMIZATION

Process optimization is used primarily for cleaning of CVD chambers, and can reduce fluorinated gas emissions through the use of endpoint detectors and/or process parameter variation to optimize the fluorinated gas use (SIA, 2007). Process optimization continues to focus on CVD chamber cleaning because it is historically the greatest source of fluorinated gas emissions. Because CVD cleaning occurs when wafers are not present in the chamber, this process can be optimized without negatively affecting wafer production (SEMATECH, 2005). Because this compliance option reduces the volume of fluorinated gases used and emitted, and does not generate by-products, staff concludes that it poses no significant environmental impacts.

2. ALTERNATIVE CHEMISTRIES/PROCESSING

The largest portion of GHG emission reductions achieved to date from the U.S. semiconductor industry is through the use of alternative chemistries, primarily from substituting NF_3 for C_2F_6 in the chamber clean process (SIA, 2007). Specifically, the industry has developed remote plasma clean technologies to replace in-situ C_2F_6 chamber cleans (SEMATECH, 2005). ARB survey results also show the use of C_3F_8 and c-C_4F_8 as alternatives for C_2F_6 in CVD chamber cleaning. Alternative gases can be used more efficiently than C_2F_6 and therefore require less gas to accomplish the cleaning task, thereby lowering emissions.

The use of C_3F_8 and c-C_4F_8 can generate CF_4 and C_3F_8 as by-products, from a few percent up to 30 percent of gas input. However, total emissions are reduced up to 90 percent compared to the use of C_2F_6 (SEMATECH, 2005). NF_3 generates a smaller percentage of the by-product CF_4 than other alternative chemistries, but can also generate more fluorine (F_2) and hydrogen fluoride (HF) emissions than fluorocarbon-based cleans. The use of NF_3 may therefore require additional treatment equipment to remove F_2 and HF from the exhaust stream.

Semiconductor operations typically treat HF exhaust streams with end–of–pipe (EOP) water scrubbers. Most semiconductor operations have a separate on-site facility designed to remove HF from the wastewater stream. The HF is converted to a neutral pH and calcium fluoride (CaF_2) is formed, which as a solid is easily filtered. The resulting wastewater is nearly free of HF and clean enough to wash down the municipal sewer (Glade, 2008). Most air districts require the use of water scrubbers, which provide 90 percent control, to remove HF from exhaust streams.

Because HF is a TAC, new and modified sources of HF emissions are subject to air district review to evaluate potential public exposure and health risk, mitigate potentially significant health risks resulting from these exposures, and decrease health risk by improving the level of emissions control. Semiconductor operations located in the Bay Area Air Quality Management District (AQMD), for example, are subject to New Source Review of TACs when sources emit more than 540 pounds of HF per year (BAAQMD, 2005).

Further public protection is provided through The Air Toxics "Hot Spots" Information and Assessment Act (AB 2588, 1987, Connelly) which requires stationary sources, such as semiconductor operations, to report the types and quantities of certain substances routinely released into the air. TACs, such as HF, are among the substances that are reportable. The goals of the Air Toxics "Hot Spots" Act are to collect emission data, identify facilities having localized impacts, ascertain health risks, notify nearby residents of significant risks, and reduce those significant risks to acceptable levels.

The additional treatment load on EOP scrubbers may require modification to the scrubber systems or installation of point–of–use (POU) scrubbers. Since by-products can be treated with water scrubbers, staff concludes that no significant adverse environmental impacts are associated with the use of alternative chemistries.

3. ABATEMENT TECHNOLOGIES

The most common technologies used to abate fluorinated gas emissions from semiconductor operations include high temperature and plasma destruction. High temperature, or thermal destruction, systems rely on fuel burners, or combustion boxes, to destroy emissions at temperatures in excess of 800 degrees C. While there are several categories of plasma destruction systems, remote plasma, described briefly in Chapter III, is used by several operations in California.

Thermal destruction systems destroy F_2, converting it to HF which is then treated with water scrubbers. As noted in the alternative chemistries section, additional modifications to scrubber systems may be necessary to handle the HF. Depending upon the type of combustor, NO_x may be generated (Semiconductor International, 2007). Inward-fired combustors minimize NO_x emissions to 1 to 10 parts per million. In semiconductor operations, combustor units emit such small amounts of NO_x that they do not currently require district permits. However, the proposed regulation would impose permitting requirements on all semiconductor operations that are installing abatement to meet the emission limits.

Remote plasma CVD chamber cleaning functions as abatement, although it is classified as alternative processing. NF_3 used in remote plasma is converted to fluorine ions at 95 percent or higher efficiency, thereby reducing emissions by 95 percent (SEMATECH, 2005). Remote clean technology using NF_3 also generates more F_2 and HF than fluorocarbon-based cleans, which again must be treated through water scrubbers to comply with district permitting requirements for TACs.

4. CALIFORNIA ENVIRONMENTAL QUALITY ACT

The California Environmental Quality Act (CEQA) requires an agency to identify and adopt feasible mitigation measures that would minimize any significant adverse environmental impacts described in the environmental analysis. The ARB staff has concluded that no significant adverse environmental impacts should occur from adoption of and compliance with the proposed regulation. This regulation reduces GHG emissions and is not expected to result in any significant adverse air quality, wastewater, or hazardous waste impacts. The NO_x potentially generated by certain thermal destruction system designs will be minimized by requiring sources to go through district permitting processes when abatement devices are installed.

D. SUMMARY OF IMPACTS ON ATMOSPHERIC PROCESSES

In this section, we evaluate the impacts on atmospheric processes. The evaluation includes our assessment on whether the proposed regulation would have a positive, negative, or no impact on these atmospheric processes.

1. IMPACTS OF PROPOSED RULEMAKING ON GROUND-LEVEL OZONE CONCENTRATIONS

Enhanced ground-level ozone formation involves the interaction between VOCs and NO_X in the presence of sunlight. The rate of ozone generation is closely related to the amount and reactivity of VOC emissions as well as the amount of NO_X emissions available in the atmosphere (Seinfeld and Pandis, 1998). Ozone, a colorless gas and the chief component of urban smog, is one of the State's more persistent air quality problems. Ninety-three percent of Californians, or 36 million people, live in areas designated non-attainment for the federal 8-hour ozone standard. It has been well documented that ozone adversely affects the respiratory function of humans and animals. Research has shown that when inhaled, ozone can cause respiratory problems, aggravate asthma, impair the immune system, and cause increased risk of premature death.

In addition to adversely affecting human and animal health, ozone affects vegetation throughout most of California, resulting in reduced yield and quality in agricultural crops, disfiguration or unsatisfactory growth in ornamental vegetation, and damage to native plants. Staff believes that this regulation will not adversely impact ground-level ozone concentrations.

E. ENVIRONMENTAL JUSTICE AND COMMUNITY HEALTH

Environmental justice is defined as the fair treatment of people of all races, cultures, and incomes with respect to the development, adoption, implementation, and enforcement of environmental laws, regulations, and policies. The ARB is committed to integrating environmental justice into all of our activities. On December 13, 2001, the Board approved "Policies and Actions for Environmental Justice," which formally established a framework for integration of environmental justice into the ARB's programs, consistent with the directive of California state law. These policies apply to all communities in California, however, environmental justice issues have been raised specifically in the context of low-income areas and ethnically diverse communities.

Our environmental justice policies are intended to promote the fair treatment of all Californians and cover the full spectrum of ARB's activities. Underlying these policies is a recognition that the agency needs to engage community members in a meaningful way as it carries out its activities. The ARB recognizes its obligation to work closely with all communities, environmental organizations, industry, business owners, other agencies, and all other interested parties to successfully implement these policies.

During the rulemaking process, ARB staff proactively identified and contacted representatives from semiconductor operations and their materials suppliers, environmental organizations, and other parties interested in semiconductor operations. These individuals participated by providing data, reviewing draft regulations, and attending public meetings.

The proposed regulation is consistent with our environmental justice policy to reduce health risk in all communities, including those with low-income and ethnically diverse populations, regardless of location. Potential risks from global warming due to GHGs can affect both urban and rural communities. Therefore, reducing emissions of GHGs from semiconductor operations will provide benefits to urban and rural communities in the State, including low-income and ethnically diverse communities. The decrease in GHG emissions will occur in areas where semiconductor operations are located, which are primarily outside of residential areas. Residents in close proximity to a semiconductor operation will not be adversely impacted.

The compounds subject to the proposed regulation are GHGs. They are not carcinogens, hazardous air pollutants or ozone precursors. Staff's qualitative health risk assessment therefore concludes that public health will not be adversely affected by the regulation. Compliance will not result in any adverse localized impacts.

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VII. ECONOMIC IMPACTS OF PROPOSED REGULATION

In this chapter, we present the estimated costs and economic impacts associated with implementation of the proposed regulation for greenhouse gas emissions from the semiconductor industry. ARB staff quantified the economic impacts to the extent feasible, but economic impact analyses can be inherently imprecise by nature. Therefore, some projections are necessarily qualitative or semi-quantitative, based on general observations about the semiconductor industry.

The economic impacts analysis for the proposed regulation provides a general picture of the economic impacts that typical businesses might encounter, but staff recognizes that individual companies may experience impacts different than those projected in this analysis. The expected capital and recurring costs for potential compliance options are presented. The costs and associated economic impacts are presented for private companies, as well as governmental agencies.

A. SUMMARY OF THE ECONOMIC IMPACTS

Overall, the costs of the proposed regulation to reduce the emissions of GHGs from the semiconductor industry are absorbable, without a major impact on the profitability or operation of the semiconductor businesses in California. Of the 85 semiconductor operations identified in a survey conducted by ARB, 23 businesses are subject to the emission standards in the regulation.

ARB staff estimates the cost of the regulation to affected businesses in California to be approximately $22 million initial capital costs and about $850,000 in annual recurring costs. This corresponds to $3.7 million annually over the useful life of the regulation, assumed to be ten years. This cost represents the capital cost of equipment, annualized over the life of the regulation plus the annual recurring costs in 2007 dollars. The cost-effectiveness is estimated to be $21 per metric ton of carbon dioxide equivalent reduced. This is in line with the cost-effectiveness estimated for similar regulations identified in the Scoping Plan.

The primary customers of semiconductor operations are other businesses in the computer, cell phone, communication, or other technology related field. These businesses then sell their products to retailers or consumers. The impact on consumers is difficult to quantify due to the indirect interaction of consumers and semiconductor businesses.

Overall, ARB expects the proposed regulation to have no significant impact on employment; business creation, elimination or expansion; and business competitiveness in California. ARB staff expects no significant impact on State agencies.

B. LEGAL REQUIREMENTS

Section 11346.3 of the Government Code requires State agencies to assess the potential for adverse economic impacts on California business enterprises and individuals when proposing to adopt or amend any administrative regulation. The assessment shall include a consideration of the impact of the proposed regulation on California's jobs, business expansion, elimination or creation, and the ability of California businesses to compete with businesses in other states.

Also, State agencies are required to estimate the cost or savings to any State or local agency and school district in accordance with instructions adopted by the Department of Finance. The estimate shall include any non-discretionary cost or savings to local agencies and the cost or savings in federal funding to the State.

Health and Safety Code section 57005 requires the Air Resources Board to perform an economic impact analysis of submitted alternatives to a proposed regulation before adopting any major regulation. A major regulation is defined as a regulation that will have a potential cost to California business enterprises in an amount exceeding $10 million in any single year. Because the estimated cost of the regulation does not exceed $10 million in a single year, the proposed regulation is not a major regulation.

C. AFFECTED BUSINESSES

Any business operating a semiconductor operation that uses fluorinated gases or heat transfer fluids will be affected by the proposed regulation. Also, businesses that are customers of semiconductor operations will be potentially affected. The focus of this analysis, however, will be on semiconductor operations because these businesses will be directly affected by the proposed regulation.

There are 85 semiconductor operations of which six are subsidiaries of another business and one is a University of California. However, four of these have plans to cease operations. All of these operations planned to cease operations before the emission standards were proposed. The largest operation that has ceased operating in California already complied with the proposed Tier 1 emission standard. Ten of the 74 semiconductor businesses in California that will be operating after 2008 already comply with the emission standards and 13 have emissions that exceed the emission standards. The remaining fifty-one businesses that emit up to 0.0008 MMT CO_2e per year are expected to be minimally impacted, incurring costs for reporting and recordkeeping requirements.

Table VII-1 shows the number of affected operations and businesses by tier.

Table VII-1
Survey Data Inputs for Cost Calculations

Category	Number of Operations in 2006	Number of Businesses in 2006	Number of Businesses Operating After 2008	Number of Complying Businesses	Number of Non-Complying Businesses
Tier 1	5	5	4*	1	3
Tier 2	11	10	7*	4	3
Tier 3	12	12	12	5	7
Reporting Only	57	51	51	51	0
Total	**85**	**78**	**74**	**61**	**13**

* From the survey, we were informed that one business in Tier 1 (already is in compliance) and three businesses in Tier 2 were planning on ceasing operation before the emission standards were proposed.

ARB has identified the following Standard Industrial Classification (SIC) categories for the affected businesses. The 13 operations that will need to reduce emissions to comply with the emission standards are in the Semiconductors and Related Devices (3674) SIC code category.

Table VII-2
SIC Codes for Semiconductor Operations

SIC Code	Description
3674	Semiconductors and Related Devices
3559	Special Industry Machinery, Not Elsewhere Classified
3825	Instruments for Measuring and Testing of Electricity and Electrical Signals
5065	Electronic Parts and Equipment, Not Elsewhere Classified

D. POTENTIAL IMPACT ON SEMICONDUCTOR BUSINESSES

Three compliance options are available: abatement, process optimization, and alternative chemistries. Any combination of these options can be used to comply with the proposed regulation. To estimate cost, staff determined which compliance options would be needed for operations to reduce emissions to comply with the emission standards. The total cost includes capital cost, annual operating cost, annual permitting cost, and annual reporting and recordkeeping cost. All dollar amounts are in 2007 dollars and the life of the regulation is assumed to be 10 years.

Thirteen businesses will need to reduce their emissions to comply with the emission standards. Capital costs for these businesses include the cost for abatement or process optimization. The capital cost assumes a 5 percent discount rate, a 10 year system life, and a Cost Recovery Factor of 0.13. This produces an annualized capital cost of $2.8 million for the 11 businesses that will need to install abatement devices. The annual operating and maintenance costs are $795,000 for these 11 businesses. Two businesses would be able to comply with the emissions standards without installing abatement devices, through a combination of process optimization and alternative chemistry.

The permitting cost is determined by using the expected incremental cost increase to local air pollution control districts. This was estimated to be $1,000 per year, per operation. Over the life of the proposed regulation, the overall cost is $110,000 for the 11 operations in California that would be required to obtain a permit for abatement equipment.

The recordkeeping and reporting cost is estimated at $600 per year for each operation. Seventy-four businesses will be required to perform recordkeeping and reporting. For the 51 businesses that are only required to keep records and submit annual reports, this will be the only cost incurred. The total annual cost from recordkeeping and reporting is estimated to be $44,400 per year. Over the life of the proposed regulation, the overall cost is $444,000. Therefore, the total annual cost is estimated to be $3.7 million. Over the life of the regulation, the total cost is $37 million. A detailed presentation of these costs is presented in Appendix C.

Cost to individuals was calculated by taking the overall annual cost and dividing by the annual processing of wafers in California. This was calculated to be 0.006 cents per square centimeter of wafer. Actual costs to individuals would be reflected in higher prices for products that contain these semiconductors and related devices. However, it is expected that costs will not be passed onto consumers because California manufacturers would need to remain competitive with manufacturers outside of the State.

The non-recurring costs are annualized into discounted, equal annual payments when multiplied with an appropriate cost recovery factor (CRF), a standardized method recommended by the Cal/EPA for annualizing costs (Cal/EPA, 1996) and is consistent with the methodology used in previous cost analyses of regulations by the ARB (ARB, 2000; ARB, 2007).

The CRF is calculated as follows:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

where,

CRF = cost recovery factor
i = discount rate (assumed 5 percent)
n = project horizon or useful life of equipment (assumed 10 years)

All costs of the control devices are annualized over 10 years. The total annualized cost is obtained by adding the recurring costs to the non-recurring costs using the CRF method. Using this method, the CRF is 0.13, which represents the portion of the initial capital cost that is repaid each year over the life of the equipment.

Staff estimated profitability impacts on businesses by calculating the decline in the return on owner's equity (ROE). The approach used in evaluating the potential economic impact of the proposed regulation on these businesses is outlined as follows:

(1) A sample of representative businesses from different tiers was selected from the list of 13 affected businesses.
(2) Estimated cost was adjusted for federal and State taxes.
(3) The three-year average ROE was calculated, where data were available, for each of these businesses by averaging their ROEs for 2005 through 2007 (Dunn and Bradstreet, 2008). ROE is calculated by dividing the net profit by the net worth. The adjusted cost was then subtracted from net profit data. The results were used to calculate an adjusted three-year average ROE. The adjusted ROE was then compared with the ROE before the subtraction of the adjusted cost to determine the potential impact on the profitability of the businesses. A reduction of more than 10 percent in profitability is considered to indicate a potential for significant adverse economic impacts.

The threshold value of 10 percent has been used consistently by the ARB staff to determine impact severity (ARB, 1990; ARB, 1991; ARB, 1995; ARB, 1998; ARB, 2000; ARB, 2005). This threshold is consistent with the thresholds used by the U.S. EPA and others.

The ROEs before and after the subtraction of the adjusted compliance costs were calculated for each business using financial data for 2005 through 2007. The calculations were based on the following assumptions:

(1) Selected businesses are representative of affected businesses;
(2) All affected businesses are subject to the highest federal and State corporate tax rates of 35 percent and 9.3 percent respectively; and
(3) Affected businesses are not able to increase the prices of their products, nor can they lower their costs of doing business through short-term, cost-cutting measures.

Given the limitation of available data, staff believes these assumptions are reasonable for most businesses at least in the short run; however, they may not be applicable to all businesses.

Typical California businesses are affected by the proposed regulation to the extent that the additional costs imposed by the proposed requirements would change their profitability. Staff estimated profitability impacts by calculating the decline in the ROE. Assuming that semiconductor manufacturers will have to absorb all of the costs associated with the regulation, the proposed regulation is expected to result in an average ROE decline of 0.4 percent, as shown in Table VII-3, which is not considered to be a significant impact on the profitability of affected businesses.

Table VII-3
Changes in Return on Owner's Equity

Tier	∆ROE
Tier 1	0.9%
Tier 2	0.05%
Tier 3	0.1%
Average	**0.4%**

Note: All ∆ROEs shown are negative which indicates a decline in profitability.

As shown in Table VII-3, the projected change in profitability of typical businesses in the semiconductor industry varied widely. This variation in the impact of the proposed regulation can be attributed mainly to the following factors. First, large businesses incur higher costs due to the quantity of wafers they manufacture. Second, small businesses are usually dependent more financially on affected products than large businesses. Finally, the performance of businesses differs from year to year. Hence, the average 2005 through 2007 financial data used may not be representative of an average-year performance for some businesses.

There will be 38 small businesses in operation after 2008 that will be affected by the proposed regulation. Thirty-three of these businesses will only be required to perform recordkeeping, and make reports. The remaining five will be required to reduce their emissions. Staff estimates that four of these businesses will need to install an abatement device, and one will comply through process optimization. The average annual cost to these businesses is $89,000 per year.

E. POTENTIAL IMPACT ON EMPLOYMENT

The proposed regulation is not expected to cause a noticeable change in California employment and payroll. According to the 2002 U.S. Census Bureau, California employment in the semiconductor and related devices industry (SIC 3674) was 39,843 in 2002, or about 24 percent of the national employment in the industry. This also represents only about 0.2 percent of the total manufacturing jobs in California. These employees working in 391 establishments generated about $2.4 billion in payroll, accounting for less than 0.5 percent of the total California manufacturing payroll in 2002 (BLS, 2008). It is assumed that the semiconductor industry has declined since the most recent data available from the U.S. Census Bureau.

F. COSTS TO PUBLIC AGENCIES

This regulation will impact two State agencies, ARB and the University of California, Berkeley, and local air pollution control districts. Districts will have primary responsibility for enforcing this regulation, and ARB will be responsible for oversight. One State agency, the University of California, Berkeley, has a semiconductor operation for research purposes. This agency will be minimally impacted, incurring costs due to reporting and recordkeeping estimated at $600 per year.

The expected incremental cost increase to air districts is estimated to be $11,000 per year. It is expected that districts will recover their costs through permit fees and GHG fees under the authority of Health and Safety Code sections 40510 and 42311.

While the proposed measure will be enforced statewide, the Bay Area AQMD and South Coast AQMD will have the most impact. More than 85 percent of the State's semiconductor operations are located in these districts. The Bay Area AQMD has adopted a GHG fee rule to help recover costs associated with enforcement. Other districts have little or no semiconductor operations.

There will not be a need to increase the ARB budget for the current fiscal year, or in the next two fiscal years. However, there will be a need to request an increase starting in the 2011-2012 fiscal year. ARB estimates a need for one personnel per year at $170,000 to handle oversight and reporting for this proposed regulation.

G. COST OF THE PROPOSED REGULATION

Based on information provided in ARB's survey of semiconductor operations in California and discussions with the semiconductor industry, staff estimated the total cost of the regulation. We considered the cost of abatement equipment, operating costs, permit fees and reporting and recordkeeping costs. Based on these analyses, the total cost to businesses is estimated to be $3.7 million annually over the life of the regulation. A detailed example of the cost calculation is presented in Appendix C. The annual cost to a typical operation that is not subject to the emissions standard is expected to be about $600 annually. The average impact for the 13 businesses that we expect would need to reduce emissions is estimated to be an annual cost of $280,000 in 2007 dollars over the life of the regulation.

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VIII. FUTURE AND ONGOING ACTIVITIES

A. FLUORINATED GAS EMISSIONS

1. EMISSION CALCULATIONS

If the Board approves the proposed regulation, ARB staff will develop a calculation tool to help the industry perform the IPCC Tier 2b emission calculations required by the regulation. Staff will confer with the industry and the districts as we develop the emissions reporting tool. The objective is to ensure that any interested owner or operator receives sufficient information to submit complete and accurate reports to the districts. The emission calculation tool will be developed for the industry's use prior to the initial report due on March 1, 2011.

2. MONITORING

AB 32 specifies that GHG reductions are to be real, verifiable and enforceable. In consultation with the districts and considering the fact that the districts have permit authority for semiconductor operations, the districts will receive the emissions reports and will carry out enforcement functions. ARB staff will support the districts as needed. This may include secondary review of emission calculations, exchanging information on new technology developments, or helping to resolve enforcement or other issues that may develop.

3. REPORTING

ARB staff will also work with the districts to evaluate the need for developing a sample format for reports to promote consistency in the information provided. The intent is to ease the reporting burden for industry and lessen the review time for district personnel. ARB staff expects that districts will specify whether reports should be filed electronically or in hard copy form.

B. HEAT TRANSFER FLUIDS

1. FURTHER RESEARCH

During the manufacture of semiconductors, heat transfer fluids (HTFs) serve as coolants in chillers, removing excess heat during operations processes. Semiconductor testing often involves heating or cooling containers of HTFs, and immersing manufactured devices into the HTFs to test their integrity. In addition, when testing the function of semiconductors, HTFs are used to remove the heat the semiconductors generate while being tested. HTFs are also used to attach semiconductors to circuit boards via solder, which may be melted by the vapor of HTF heated to its boiling point. Finally, HTFs may serve to cool semiconductors and other devices or systems that generate high heat during operation (U.S. EPA, 2006).

While HTFs are contained in closed-loop systems, evaporative losses do occur over time from equipment operation. Losses may also occur when filling newly purchased equipment. Since HTFs have long atmospheric lifetimes and high global warming potential their contribution to global warming is a concern.

HTFs are used in semiconductor operations separate from CVD chamber cleaning and etching. Therefore, they are not subject to the proposed emission standards. However, ARB staff will continue to research their use and rely upon IPCC methodologies in quantifying evaporative emissions from HTFs.

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